Seasonal and annual variations of satellite-derived snow parameters in Greenland

Teruo Aoki[1], Katsuyuki Kuchiki[1], Tomonori Tanikawa[2], Masahiro Hori[2], Masashi Niwano[1], Rigen Shimada[3], Knut Stamnes[4], Wei Li[4], Hiroki Motoyoshi[5], and Alex Kokhanovsky[6]

[1]MRI, JMA, [2]EORC, JAXA, [3]Chiba Univ., [4]SIT, [5]NIED, [6]Univ. Bremen

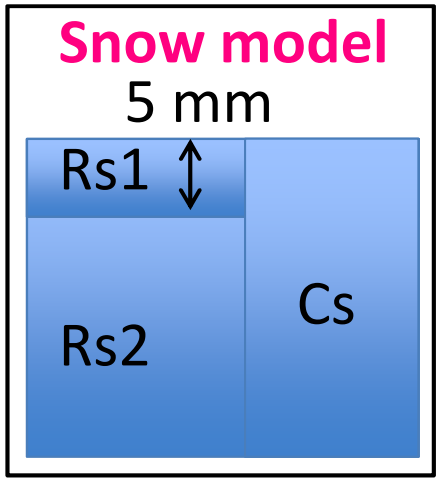
Acknowledgement: Voronoi aggregates scattering code is supplied by Kazuhiko Masuda and Hiroshi Ishimoto of MRI.

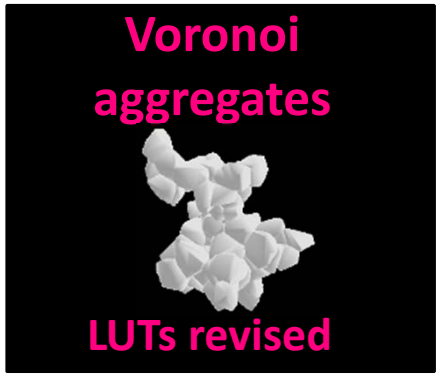
Background and goal of this study

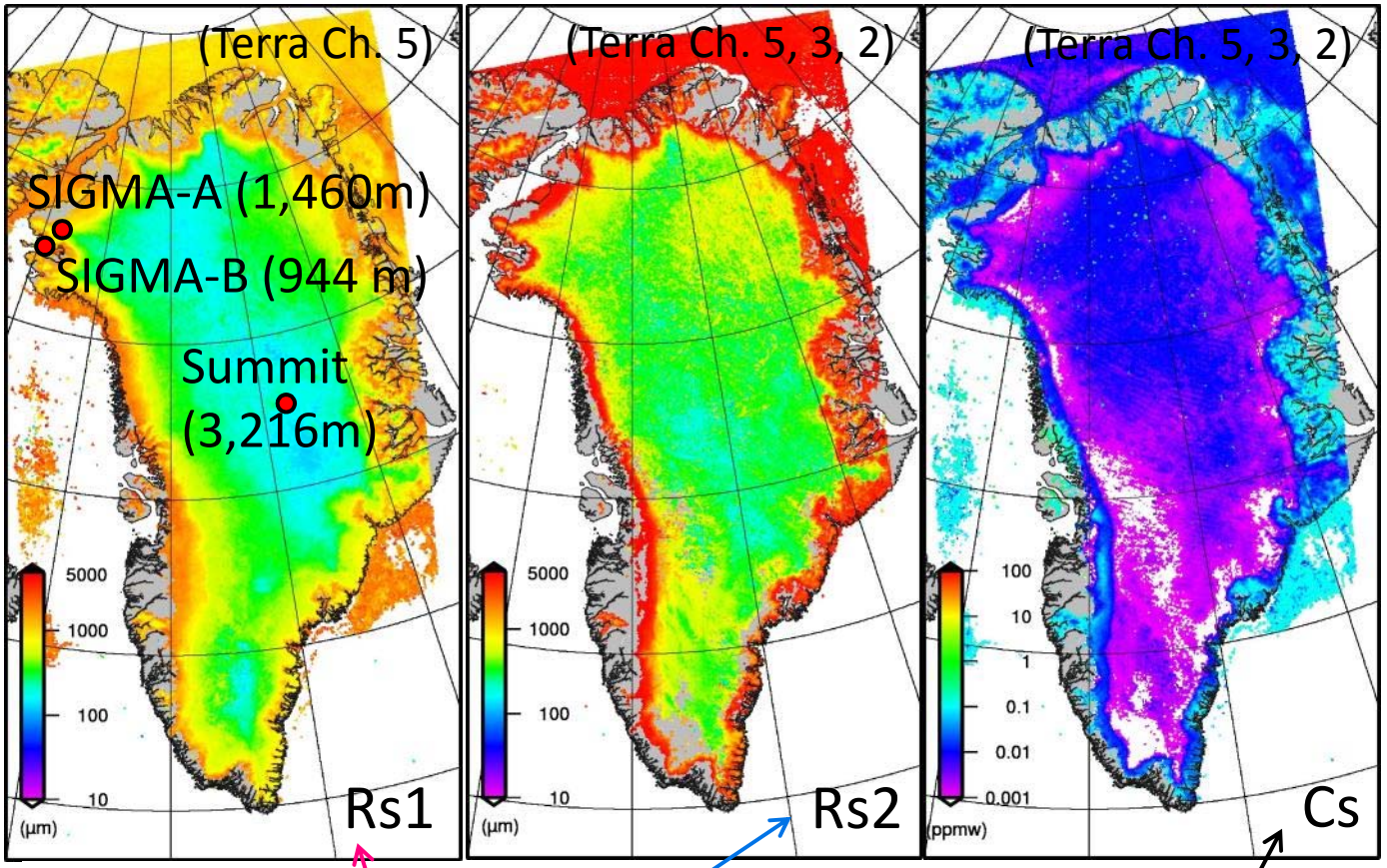
- ✓ Snow and ice in the Arctic are presently undergoing drastic changes. However, the accuracy of numerical climate projection is not enough.
- ✓ One possible cause of the uncertainty is changes of snow and ice conditions (snow grain size, impurities [BC and dust], albedo, etc.) near the surface because snow albedos strongly depend on snow grain size and snow impurities.
- ✓ Long-term monitoring of those snow parameters using satellite remote sensing is important as well as snow process study and modeling.

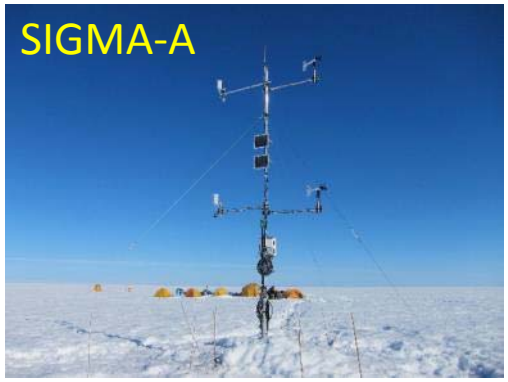
Target snow parameters	
Topmost snow grain size	SNGST
Subsurface snow grain size	SNGSS
Snow impurity (soot) concentration	SNIP
Snow and ice classification	SIC
Snow and ice surface albedo	SIALB
Ice sheet surface roughness	ISRGH

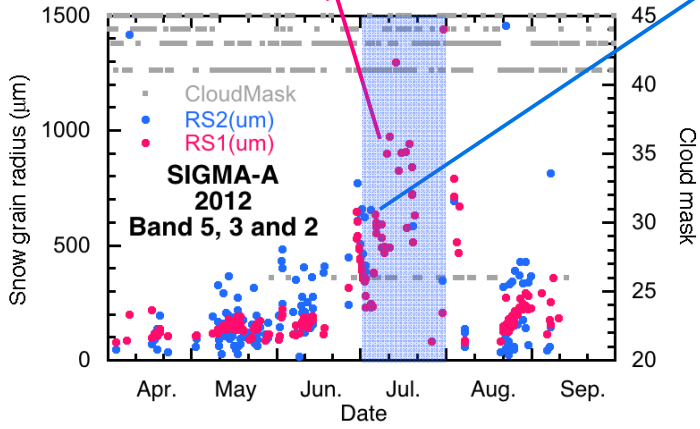
Monthly averages of snow parameters in July, 2012

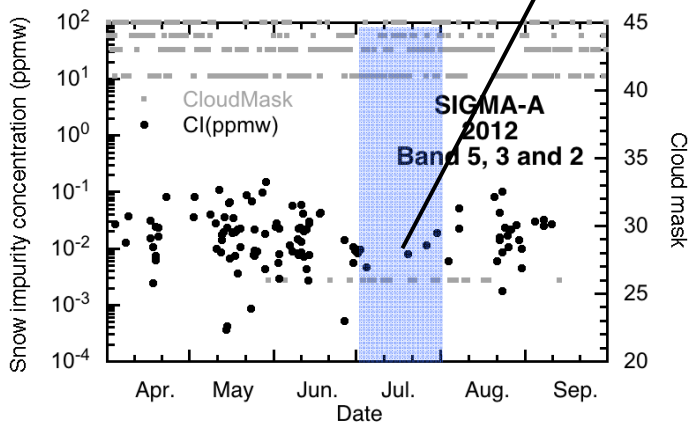












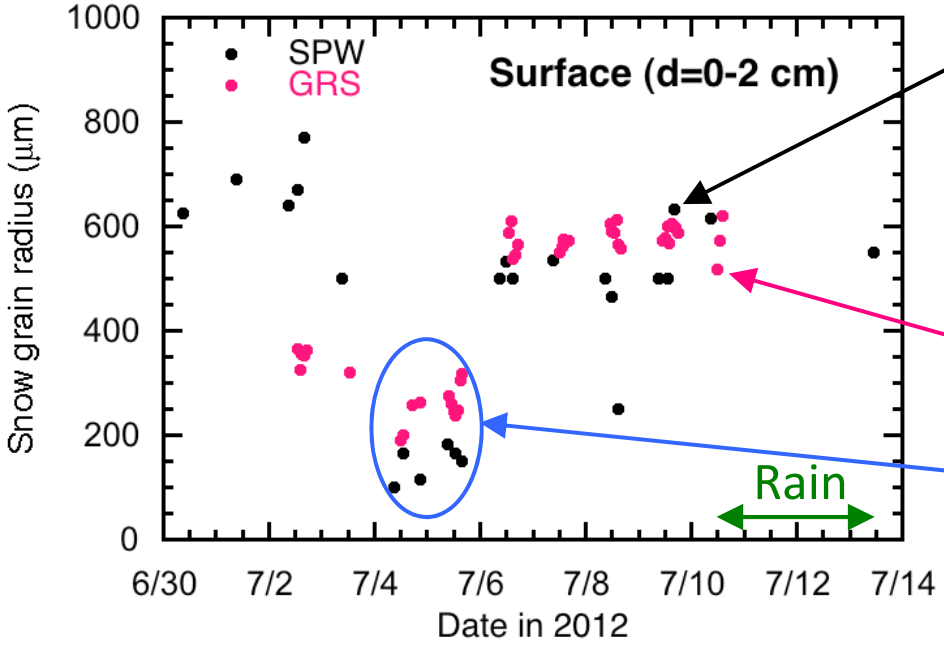
Snow grain size measurements

Snow pit work (SPW):

- ✓ Snow grain size measured using a handheld lens (Aoki et al., RSE 2007) at snow pit work

Ground-based remote sensing (GRS)

- ✓ Optically derived snow grain size using spectral albedo at λ = 1.2 μm measured with a spectrometer (Kuchiki et al., AO 2009)

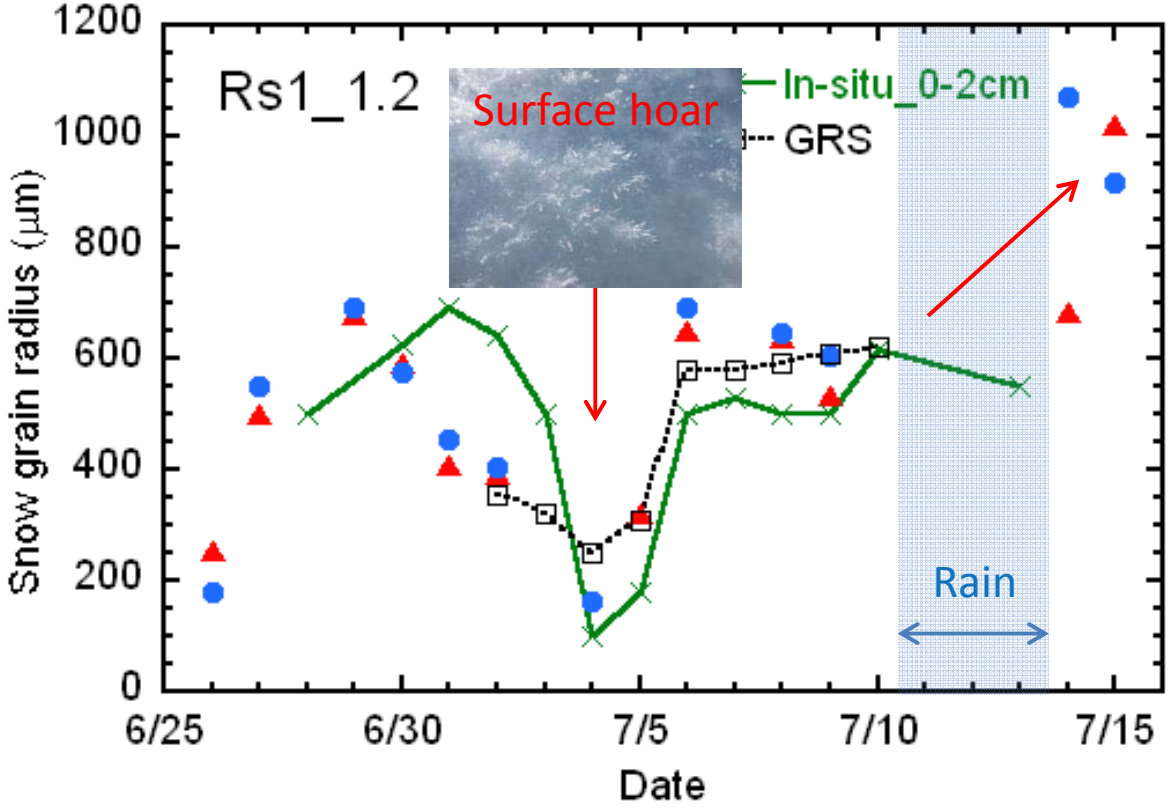


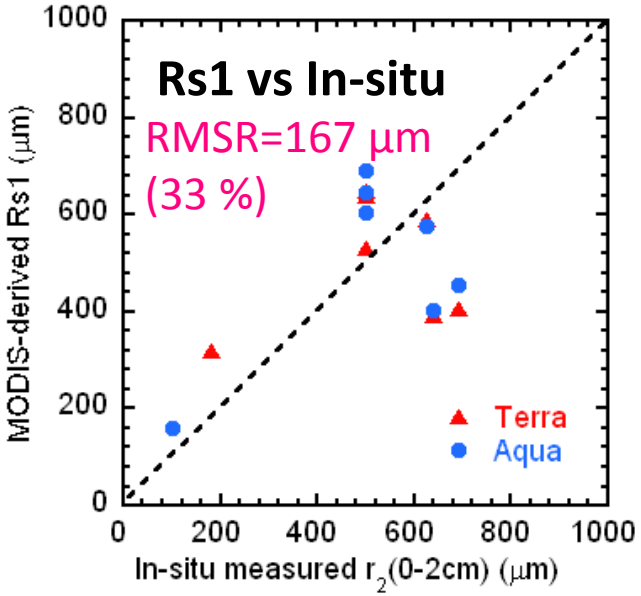
- ✓ SPW agreed well with GRS at λ = 1.2 μm.
- ✓ Small grain size around 5 July was due to surface frost.

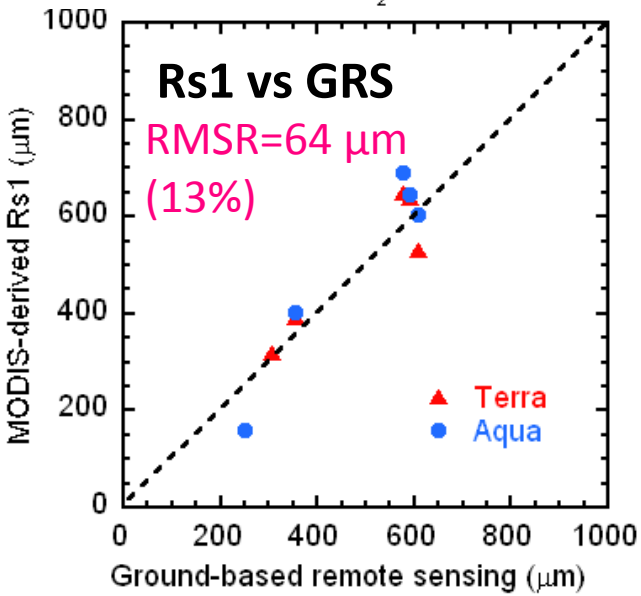
Topmost snow grain radius Rs1

Snow grain model:
Voronoi aggregates

SIGMA-A in 2012

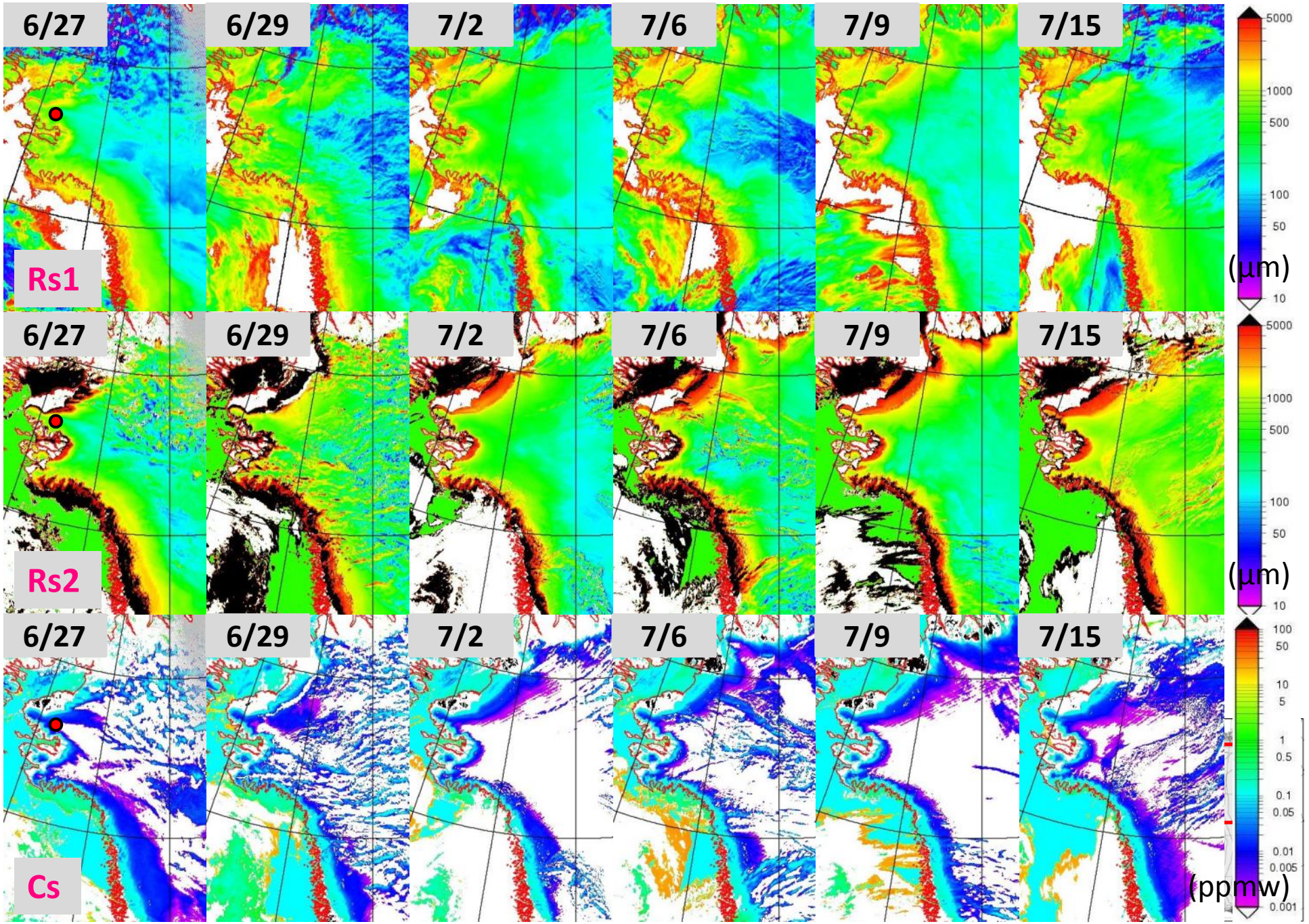


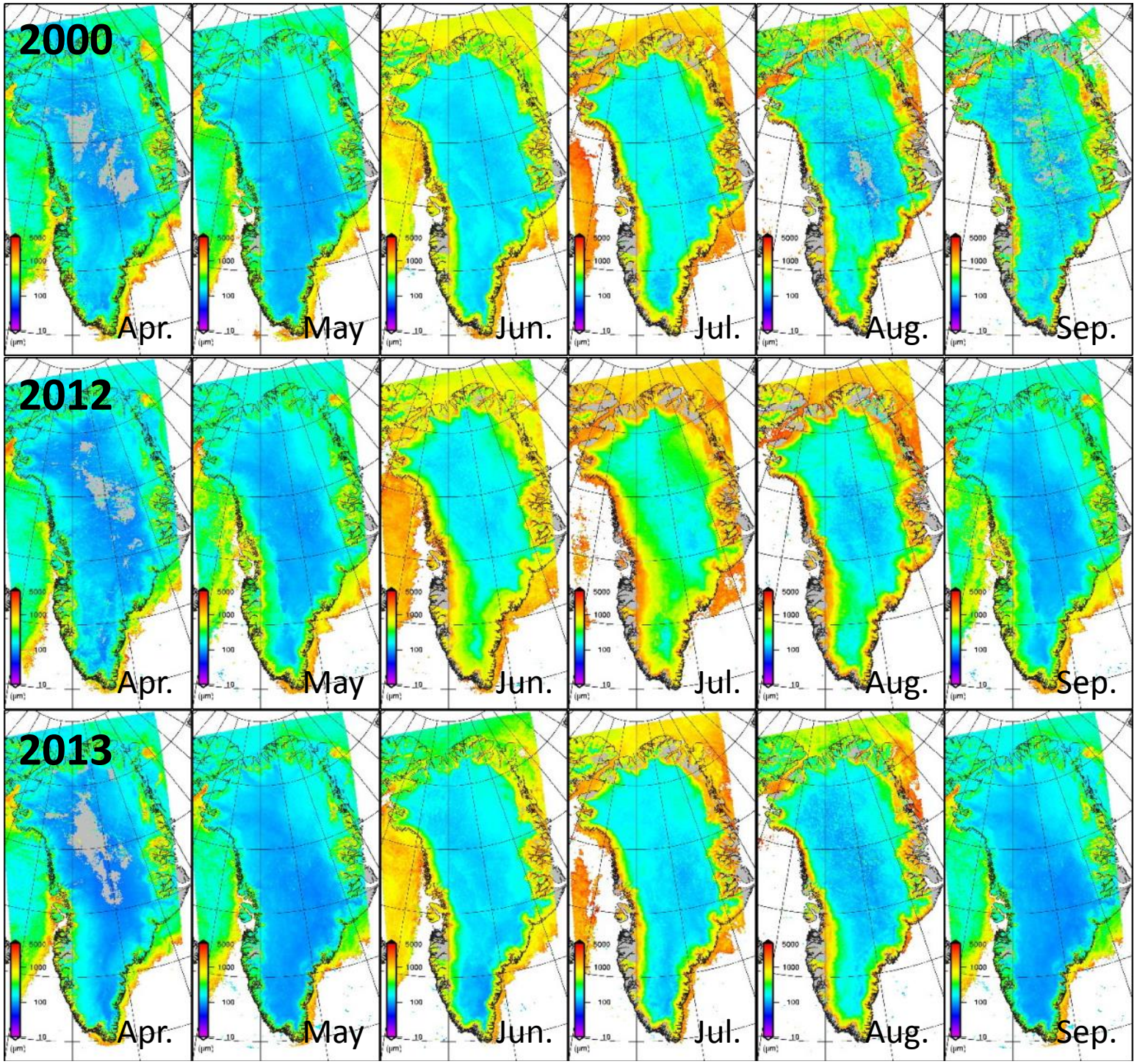




- ✓ Satellite derived Rs1 successfully captured the snow grain size variation (surface frost, rainfall).
- ✓ Rs1 retrieved from Terra/Aqua MODIS agreed well with the in-situ measurements and the GRS using spectral albedo data.

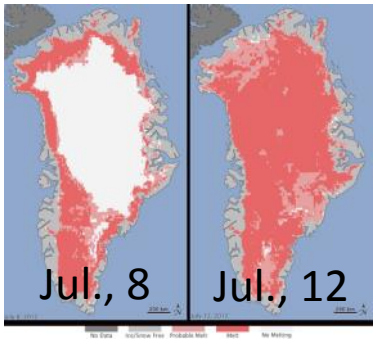
Topmost (Rs1) and subsurface (Rs2) snow grain radius and soot con. (Cs) in NW Greenland, 2012



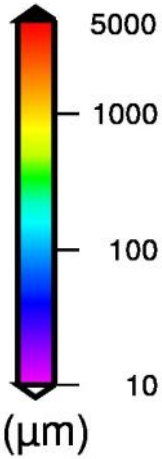


Seasonal variation of snow grain size Rs1 (d < 5 mm)

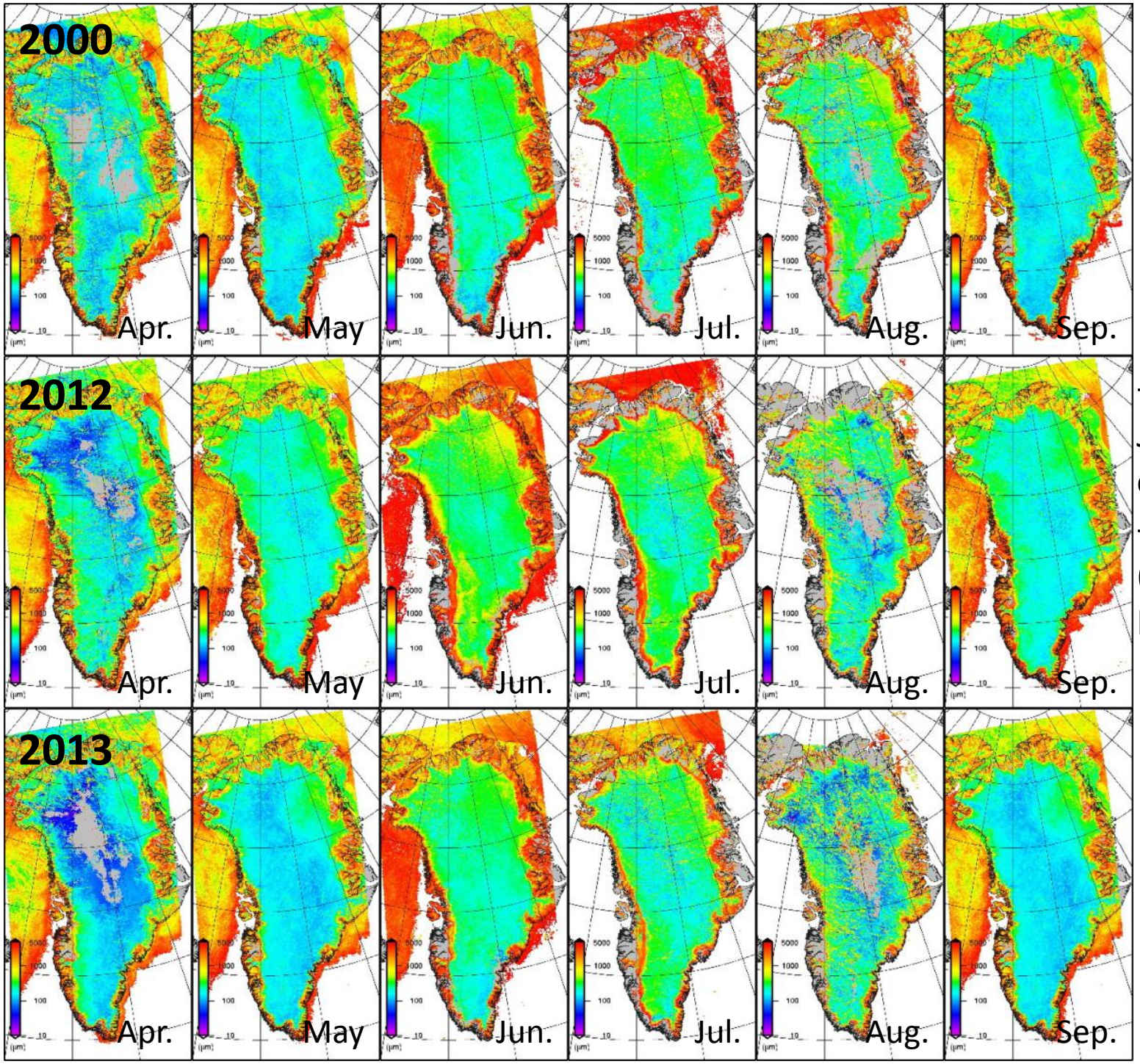
Record melting event occurred



<- Cold summer

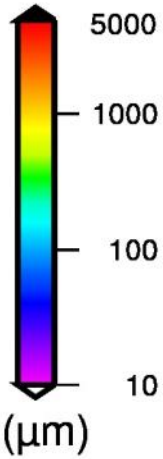


(Terra Ch. 5)

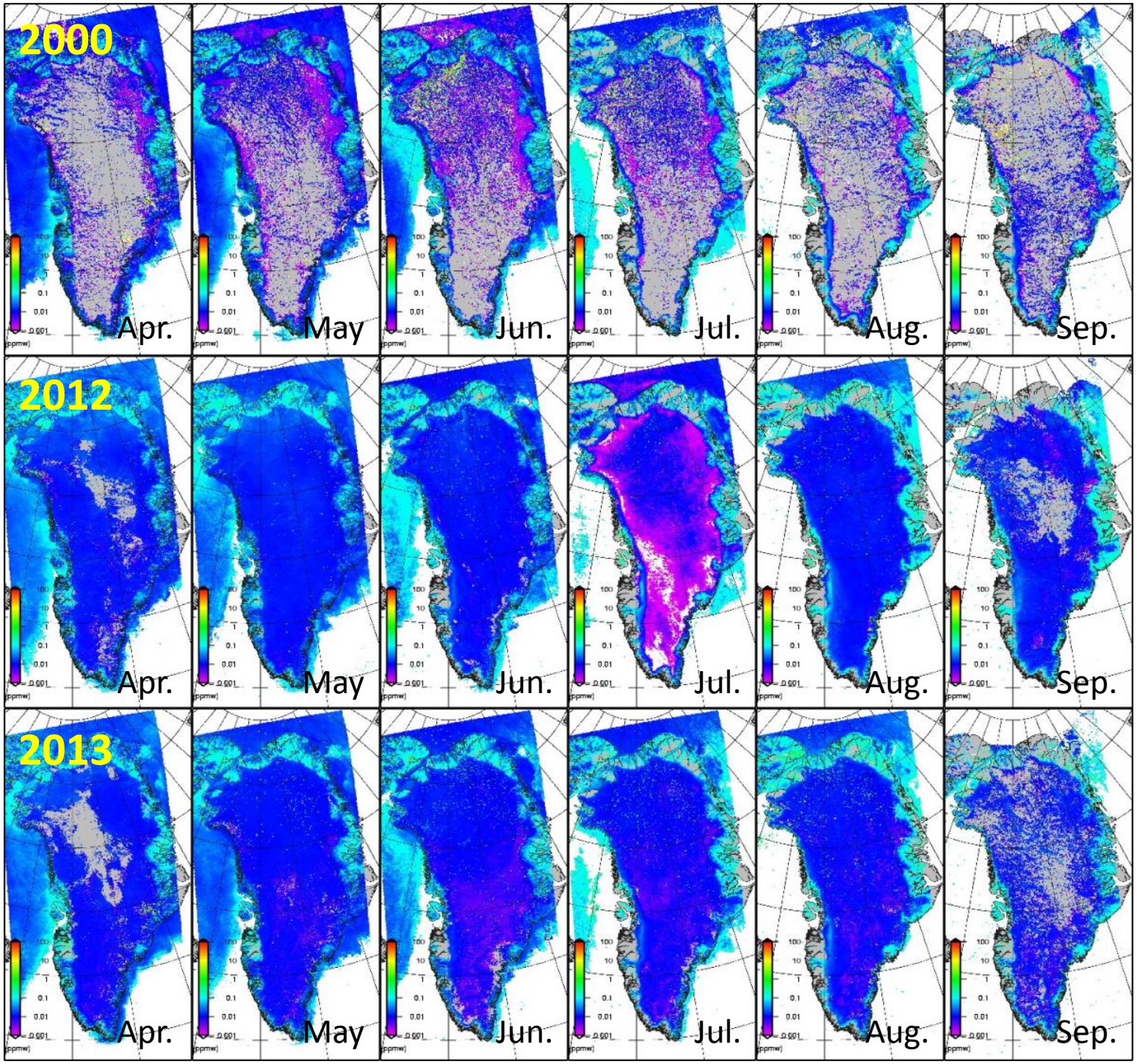


Seasonal variation of snow grain size Rs2 (d > 5 mm)

- Rs2 in June and July are larger in each year.
- Same tendency (large in 2012) as Rs1.

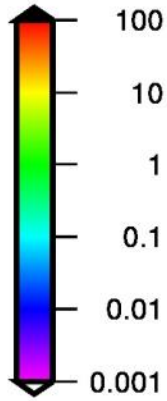


(Terra Ch. 5, 3, 2)



Seasonal variation of snow imp. Conc. (Cs)

- Higher Cs in 2012 and 2013 are due to the degradation of Ch.3 (0.46 µm).
- Lower values in July, 2012?

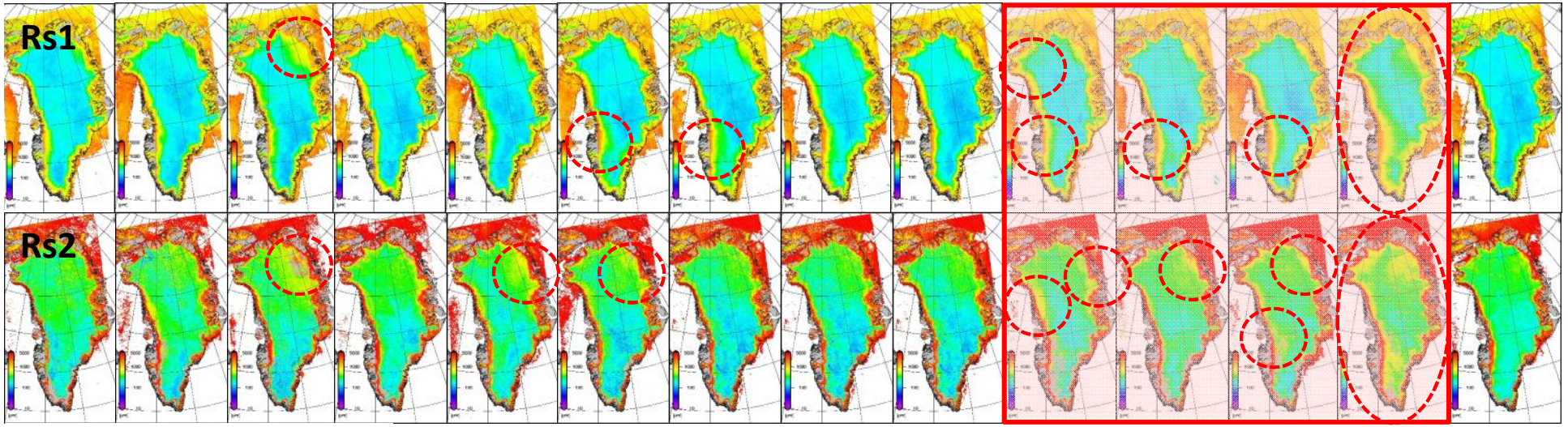


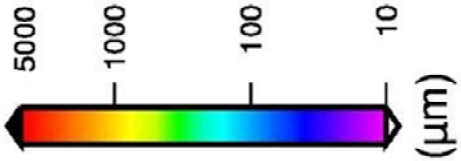
(Terra Ch. 5, 3, 2)

Annual variations of snow parameters

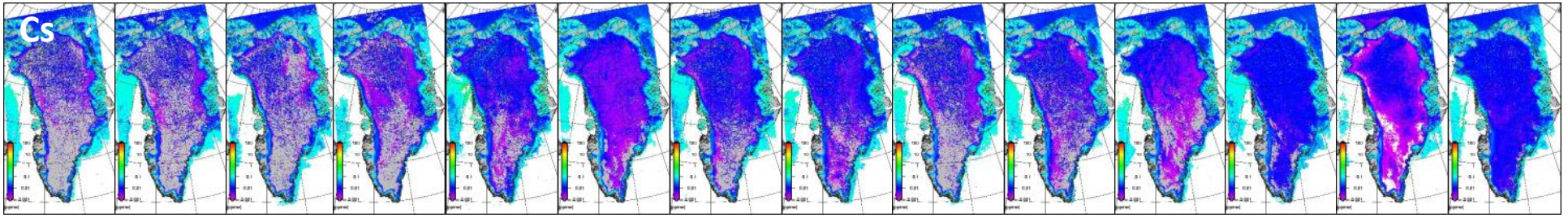
(Terra Ch. 5, 3, 2)

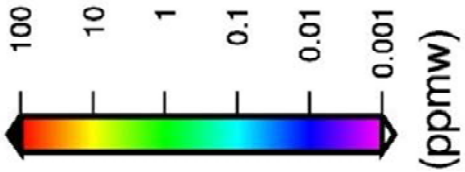
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013



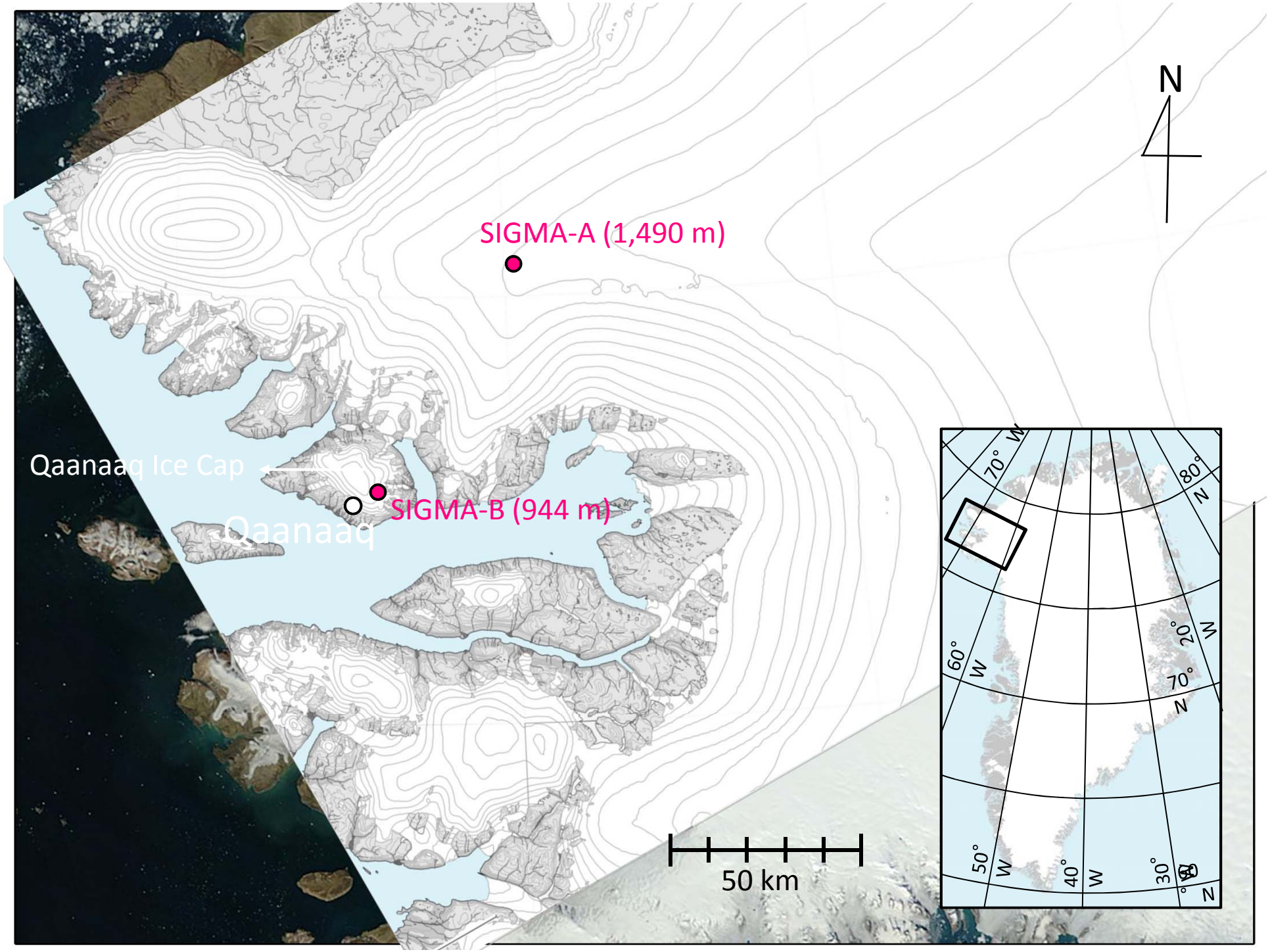


- ✓ The area of large grain size changes year by year.
- ✓ There is no constant increasing trend, but the larger values were observed in recent years (2009-2012) and especially for 2012 the remarkable increase in whole Greenland.

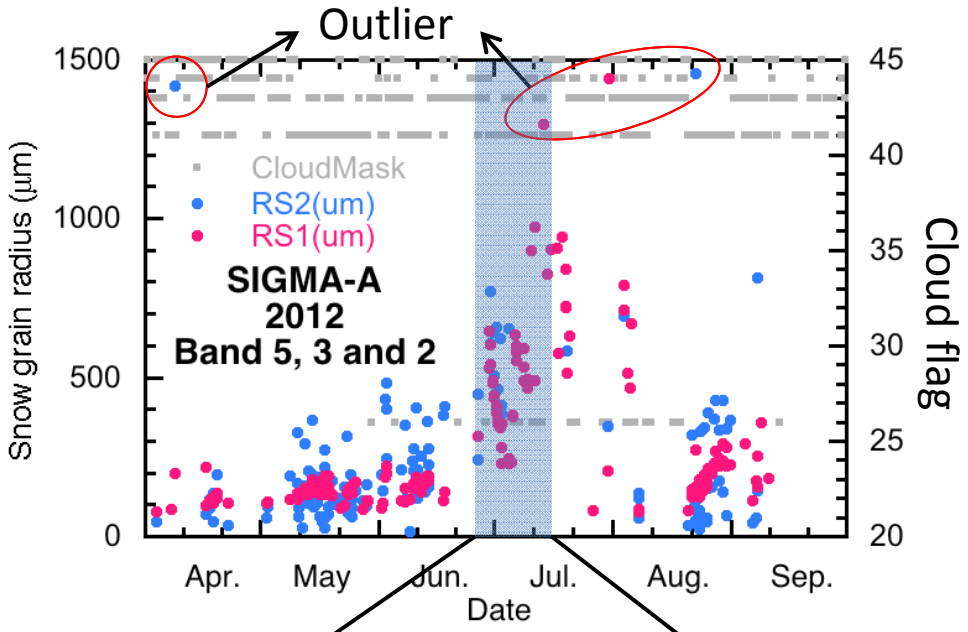




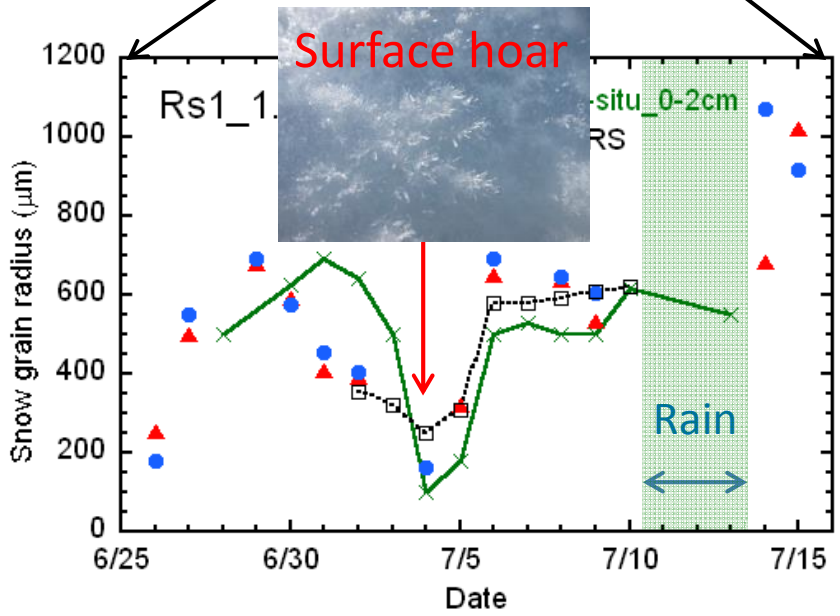
- ✓ Increasing trend is attributed to a degradation of Ch.3.
- ✓ In-situ measured soot background conc. in the past were around 0.001 ppmw, which is less than detection limit.

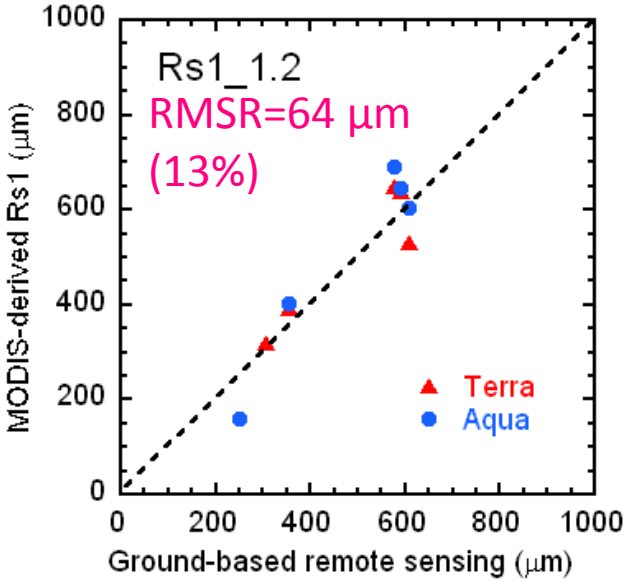

N
SIGMA-A (1,490 m)
Qaanaaq Ice Cap
SIGMA-B (944 m)
Qaanaaq
50 km
70° W
80° N
60° W
20° W
70° N
50° W
40° W
30° W
80° N

Effects of solar geometry on retrieval results

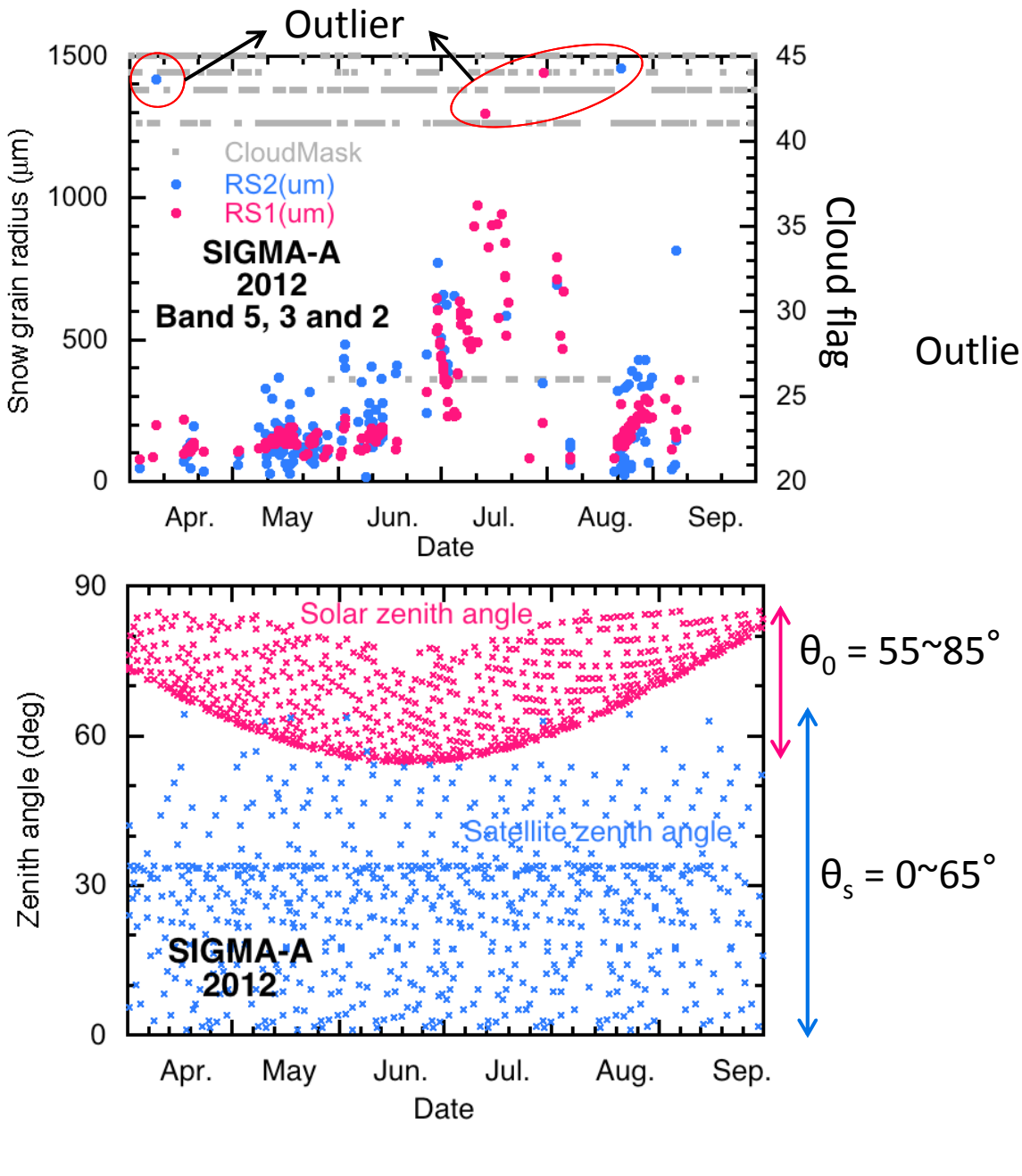


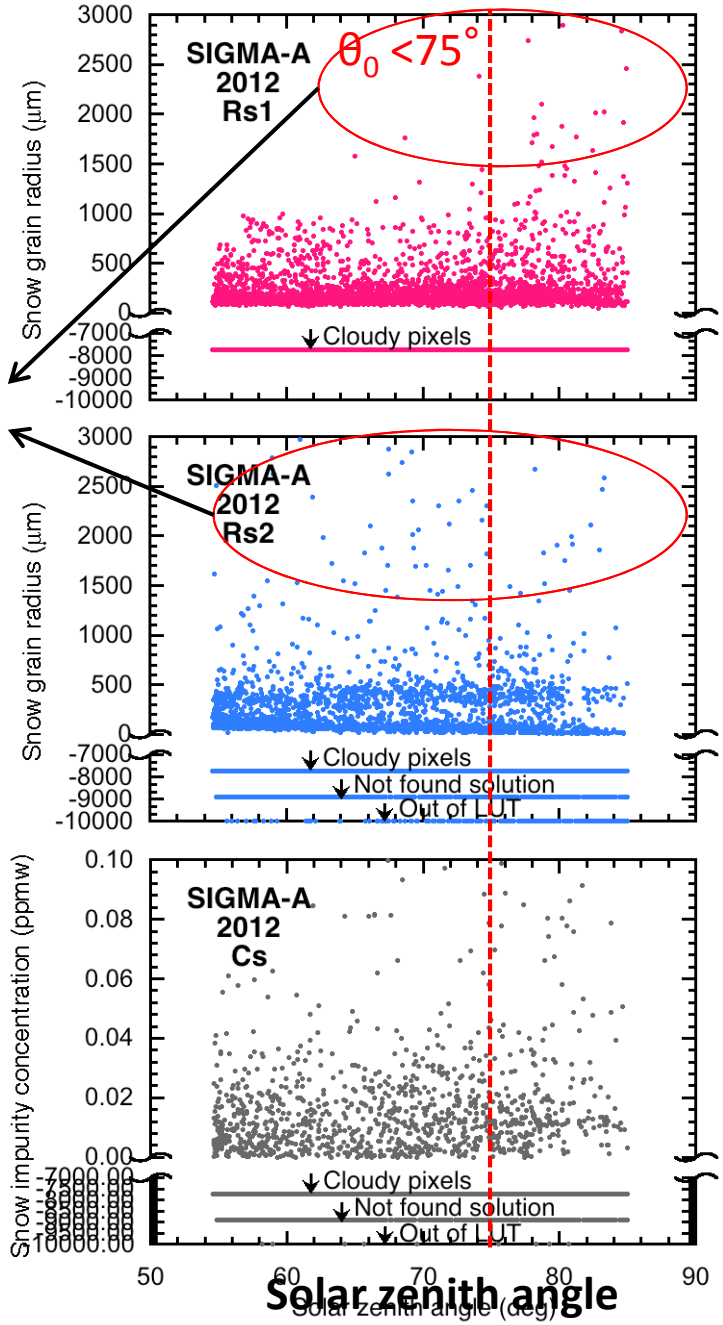
Validation at SIGMA-A in 2012



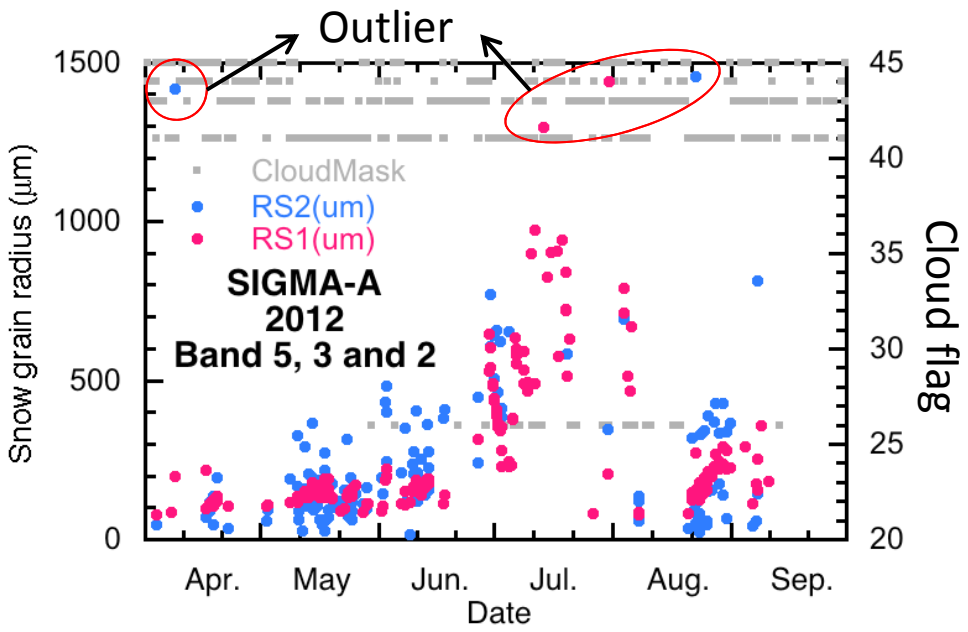


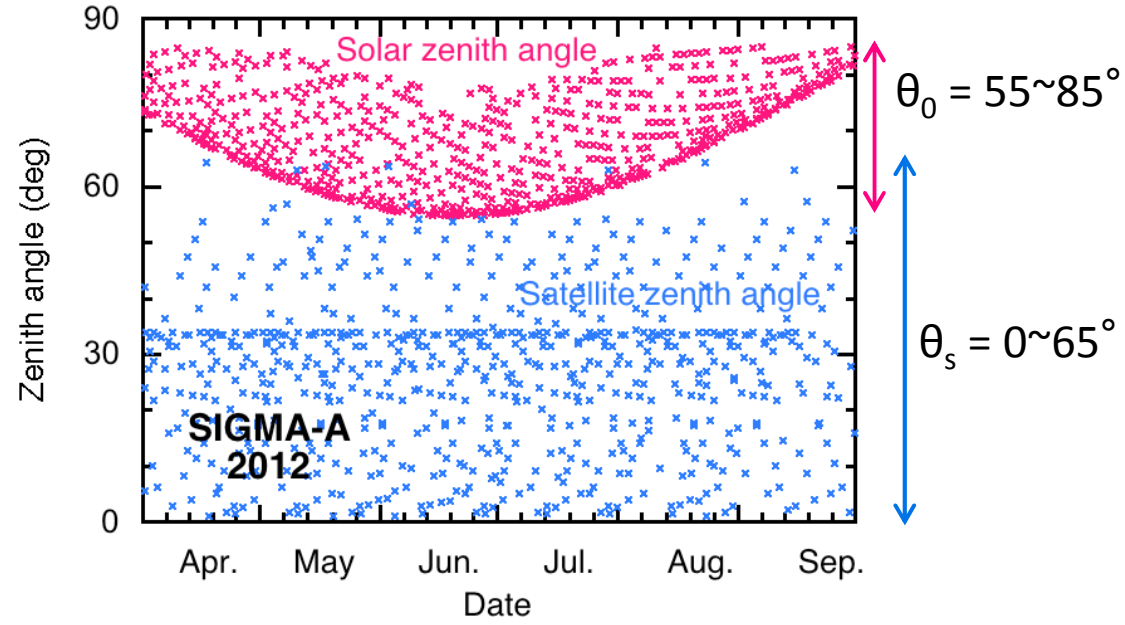
Effects of solar geometry on retrieval results

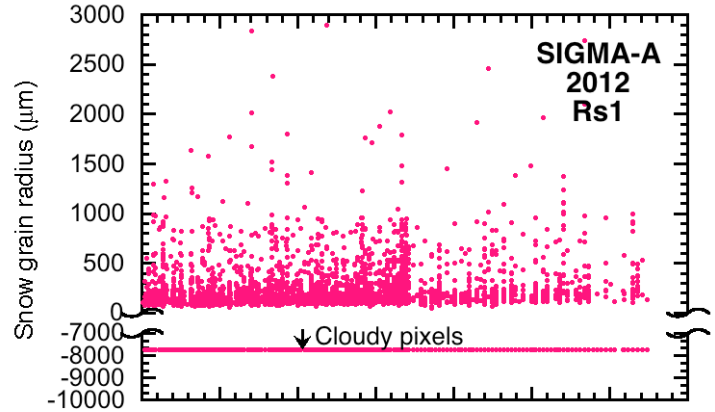


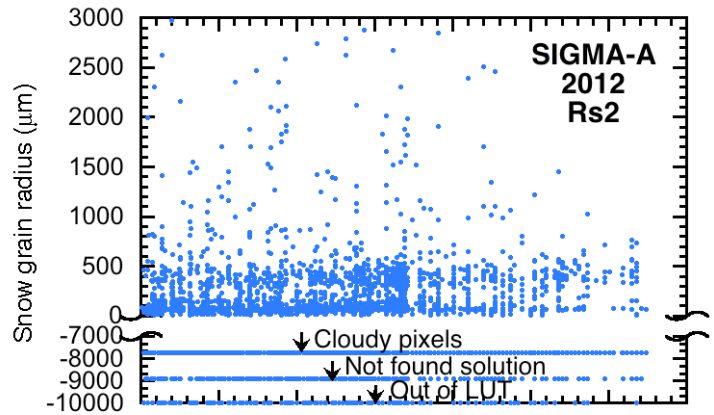


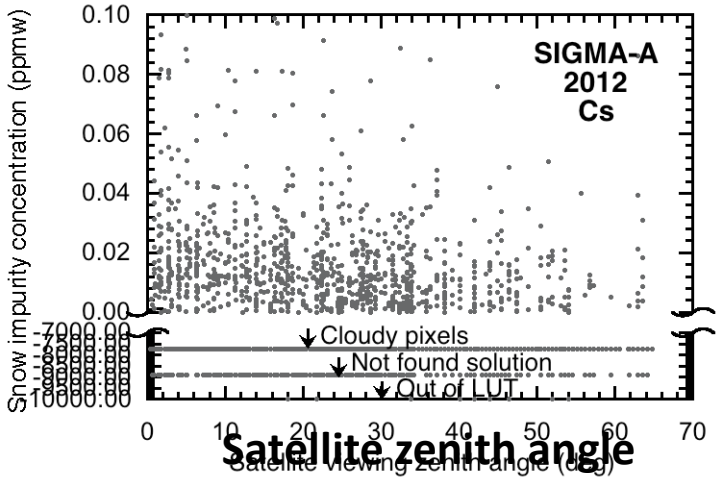
Effects of satellite and solar geometry on retrieval results





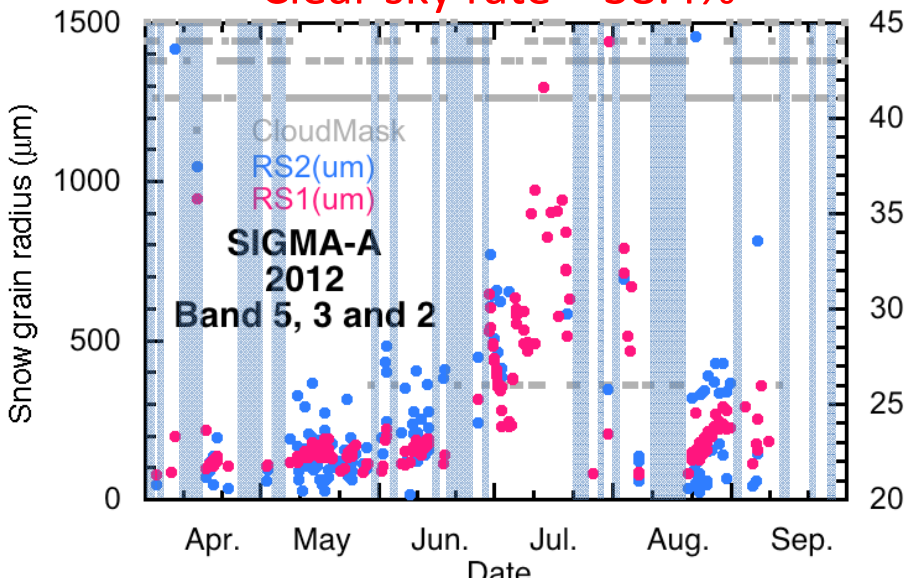




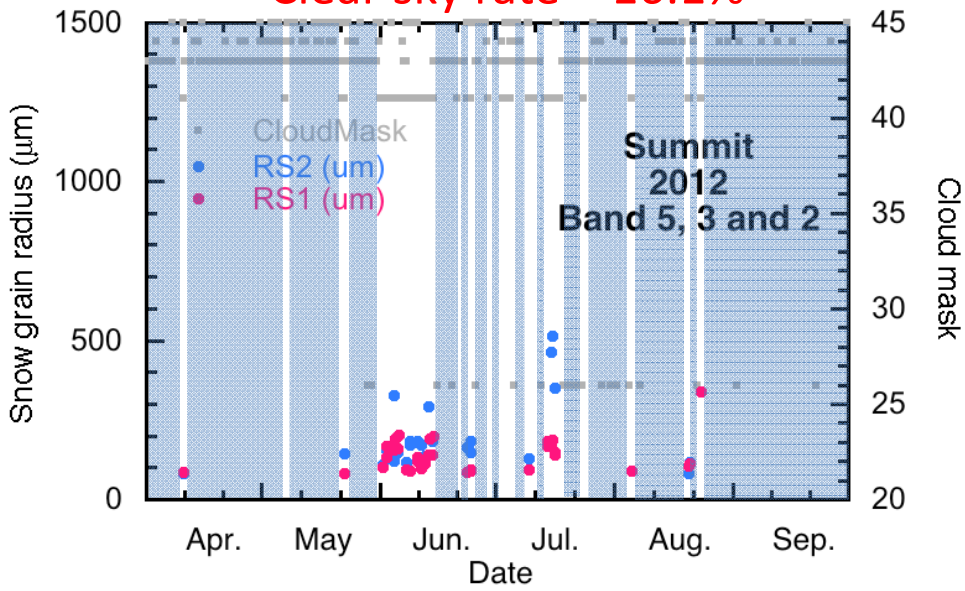


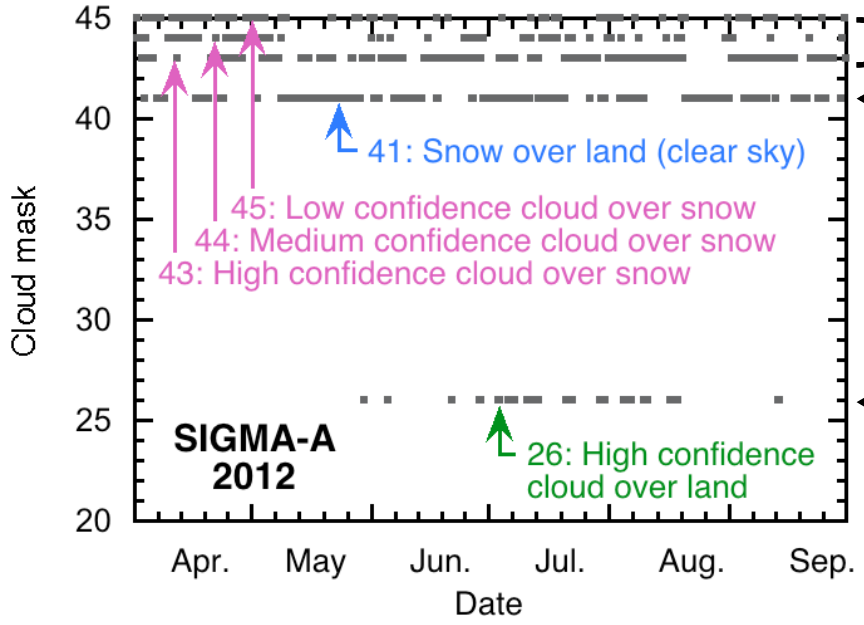
Cloud detection accuracy of SK code

Clear sky rate = 38.4%



Clear sky rate = 16.1%





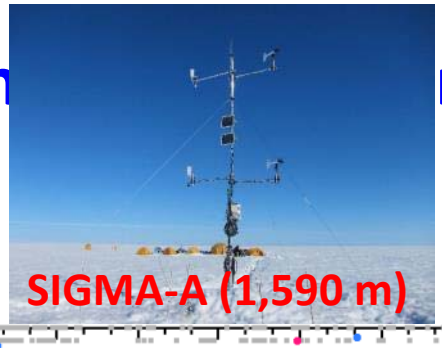
Cloudy sky

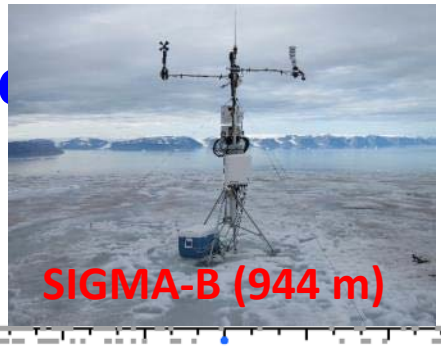
Clear sky

False discrimination

- ✓ False discrimination for high confidence cloud over land in summer.
- ✓ Cloud cover overestimate over high elevation area (Summit, 3,216 m).

Sn ret erenc

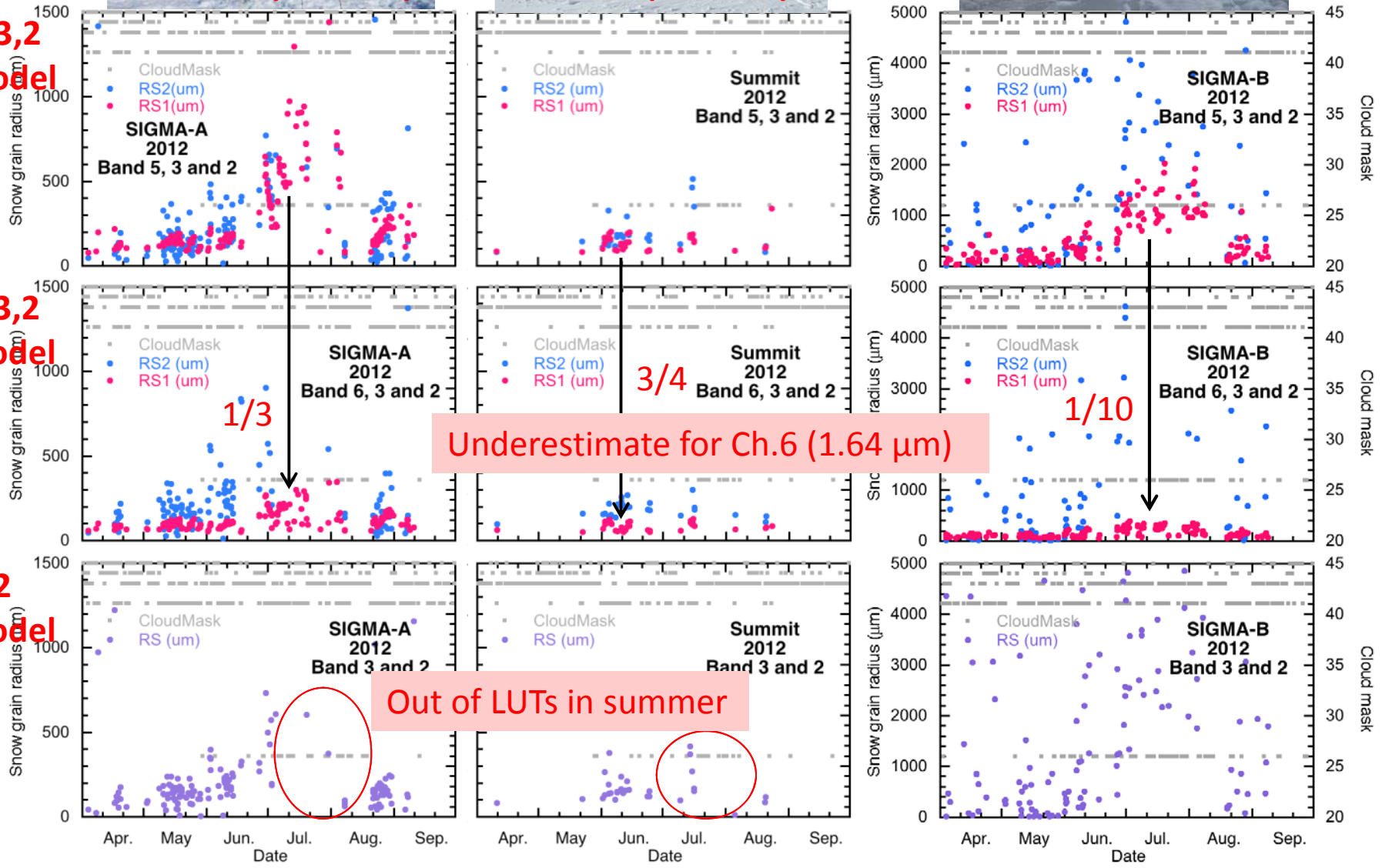




Ch.5,3,2
2L model

Ch.6,3,2
2L model

Ch.3,2
1L model



Conclusions

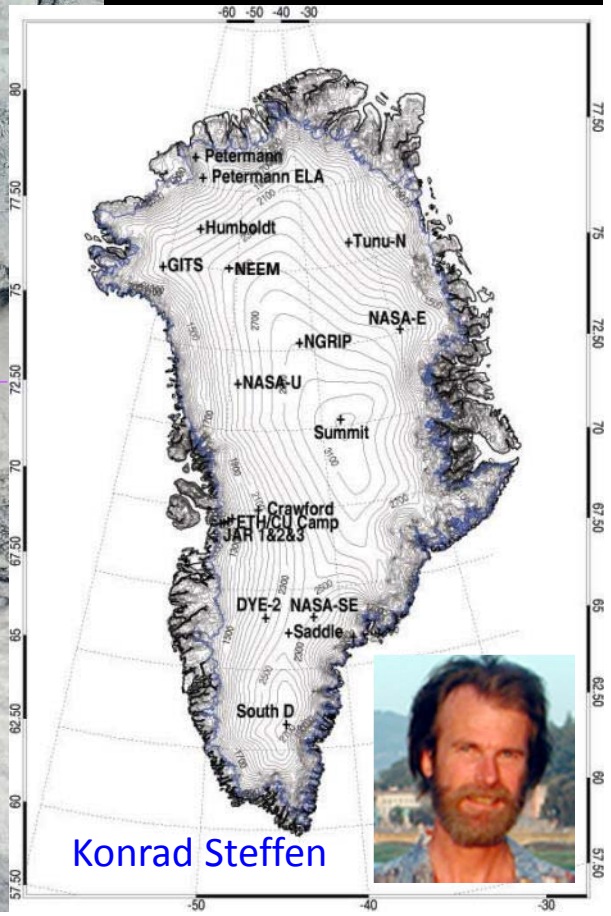
- ✓ Snow grain sizes and impurity concentration are retrieved in Greenland with MODIS data using improved LUTs calculated by Voronoi aggregate single scattering model.
- ✓ Seasonal and annual variations of snow parameters from April to September for 2000-2013 are investigated .
- ✓ Snow grain sizes in June - August were increasing in each year.
- ✓ There was no constant increasing trend in snow grain size, but the larger values were observed in recent summers (2009-2012), the remarkable increase was observed for whole Greenland in 2012.
- ✓ There are some issues to be improved for the algorithms as:
  - False “high confidence cloud over land” was discriminated over ice sheet in summer.
  - Cloud cover was overestimated over high elevation area (Summit, 3,216 m).
  - Snow grain size with Ch.6 (1.64 μm) is underestimated , which is enhanced for larger grain size.
  - Retrievals by two-channel method with Ch.3 (0.46 μm) and Ch.2 (0.86 μm) using one-snow layer model were sometimes out of LUTs in summer season.

Appendix

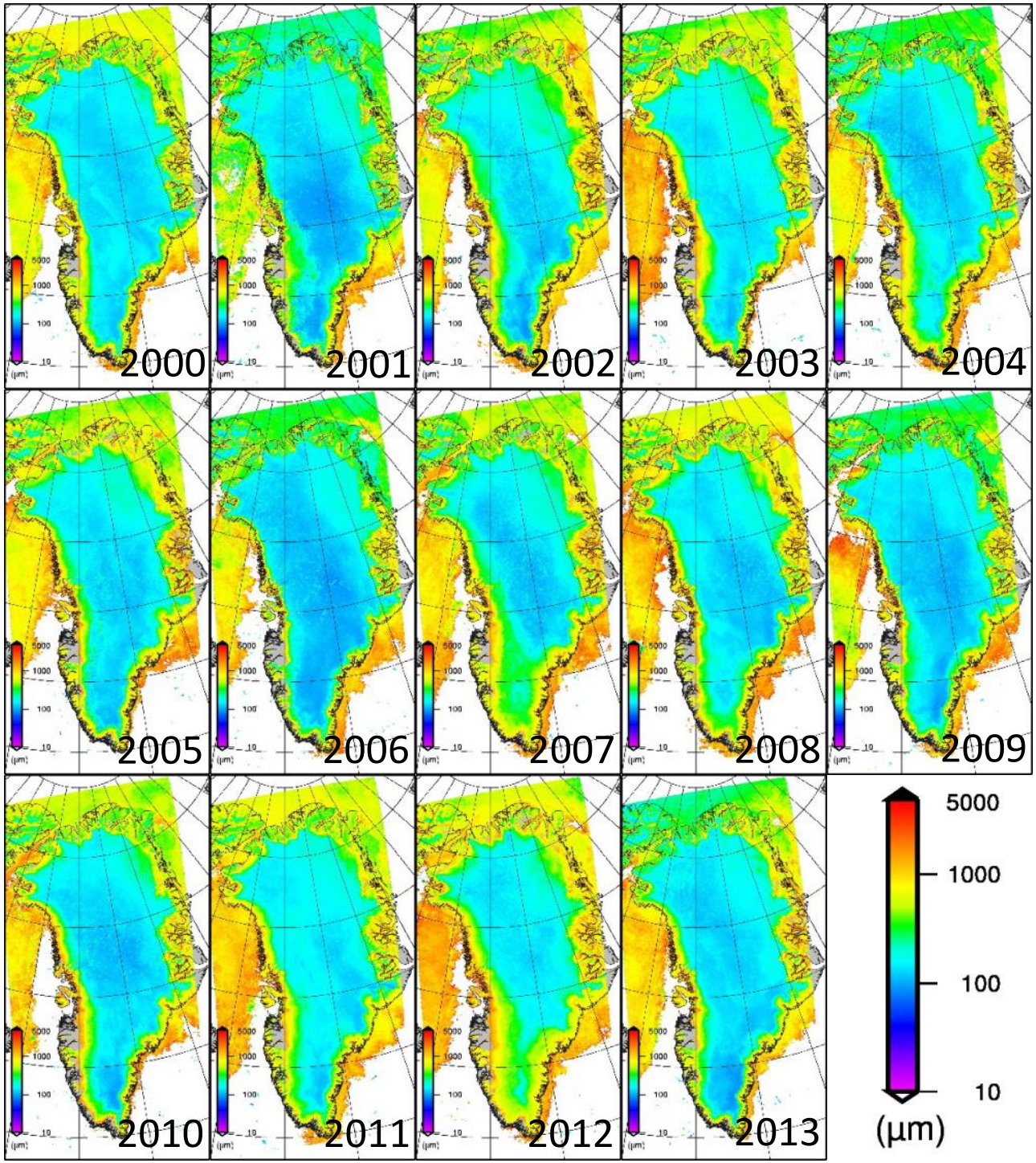
Terra/MODIS RGB composite image over Greenland

Qaanaaq
P2
SIGMA-A (1,490m)
Thule Air Base
NEEM(2,484m)
Steenstrup Gl. AWS (190m)
P3
P5
Upernavik
P4
P6
Ilulissat
Koni Steffen's AWSs
Swiss Camp (1,149m)
568-2,022m
?
Kangerlussuaq
von den Broeke's AWSs
490-1,520m
Nuuk
Copenhagen

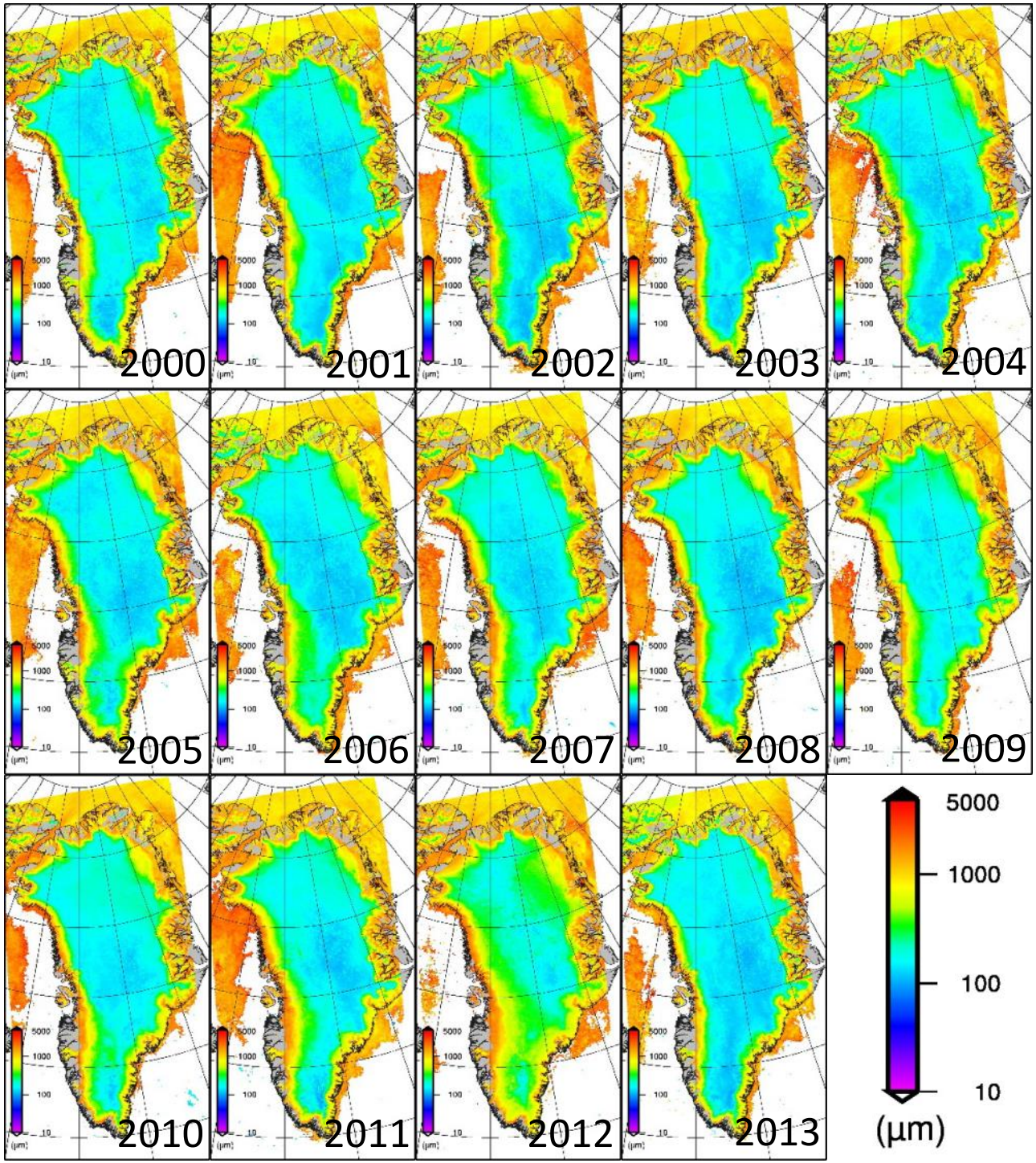
↓ Greenland Climate Network (GC-NET): AWS network



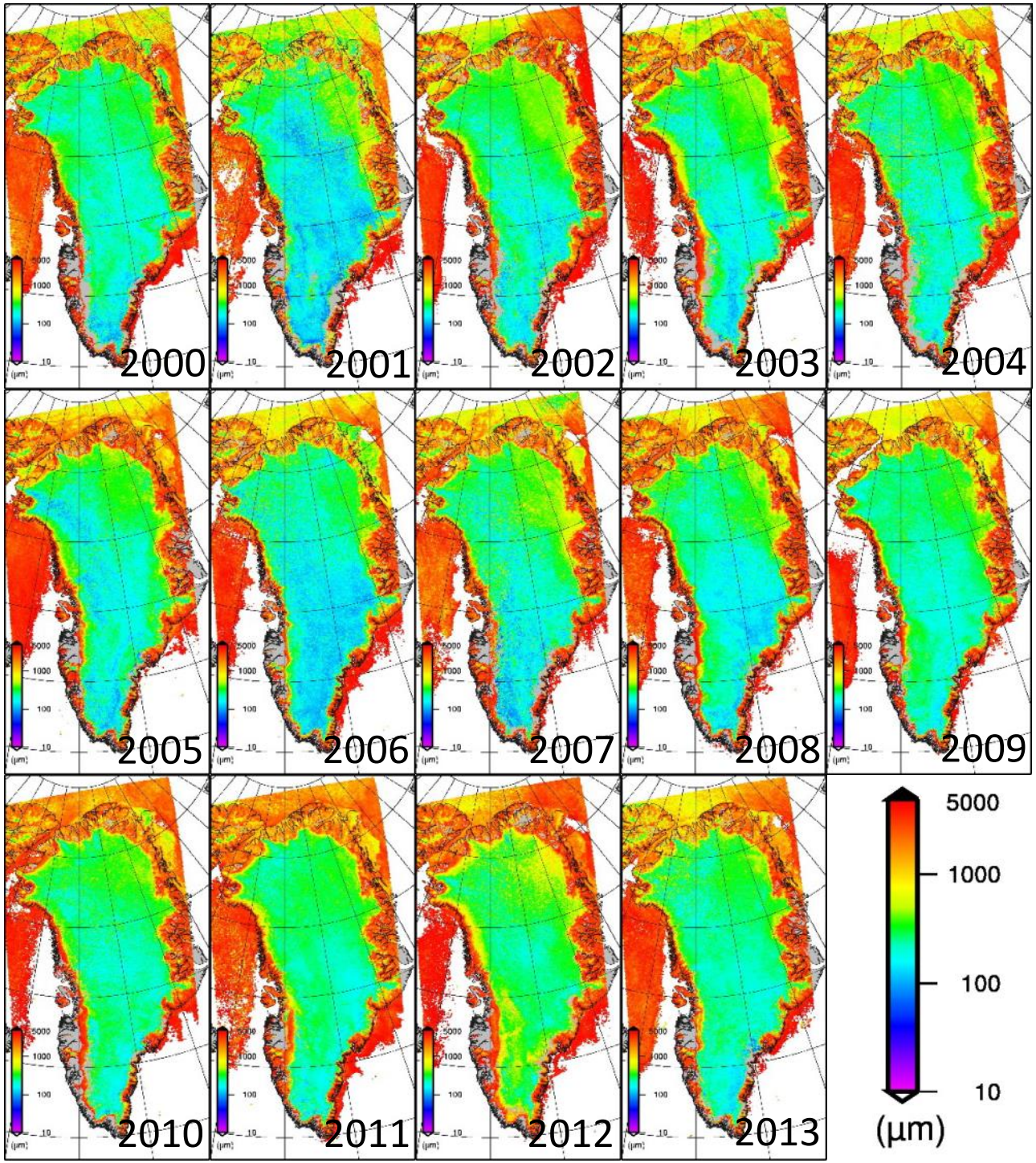
Konrad Steffen



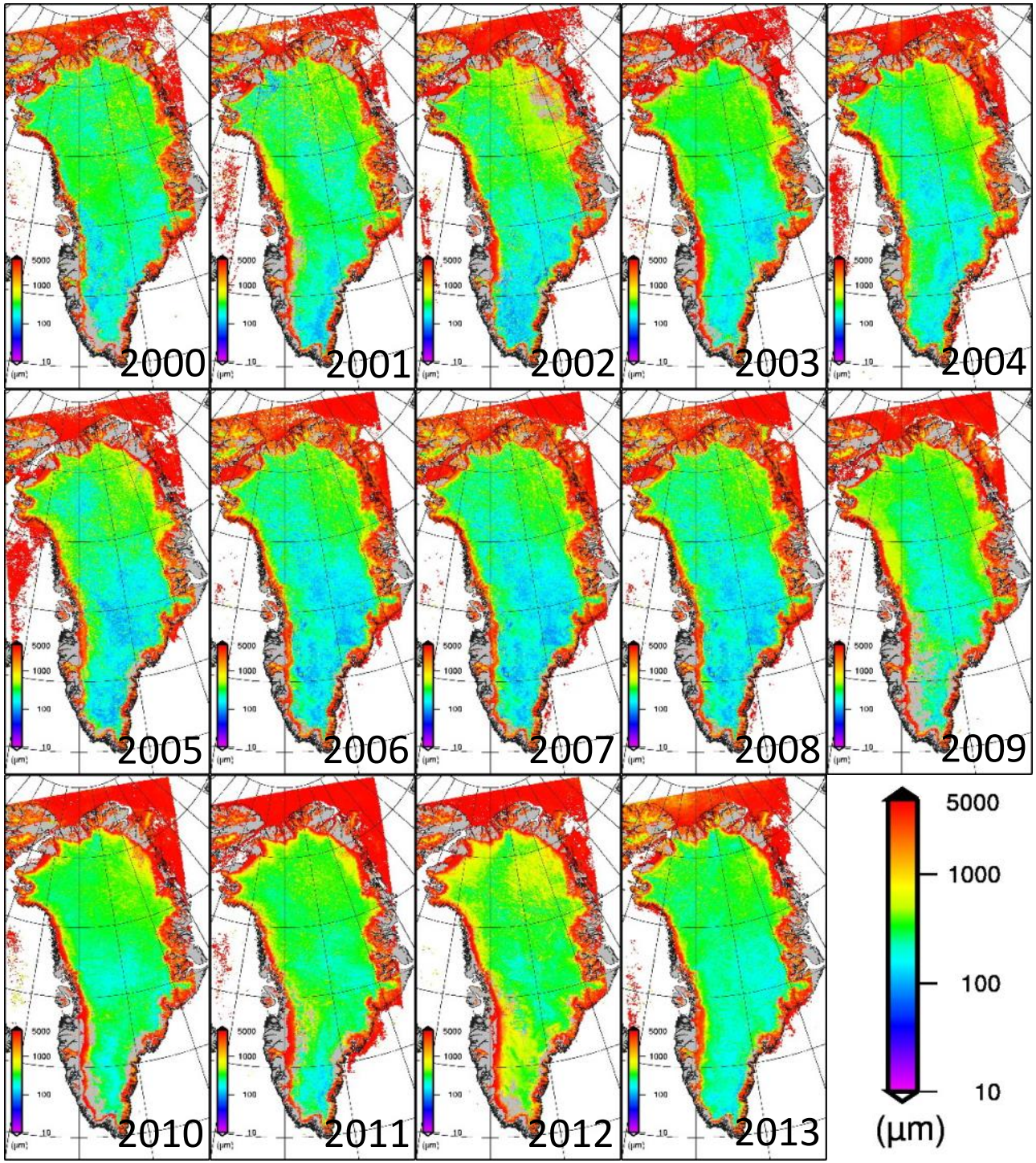
Snow grain size (Rs1) - monthly average in June



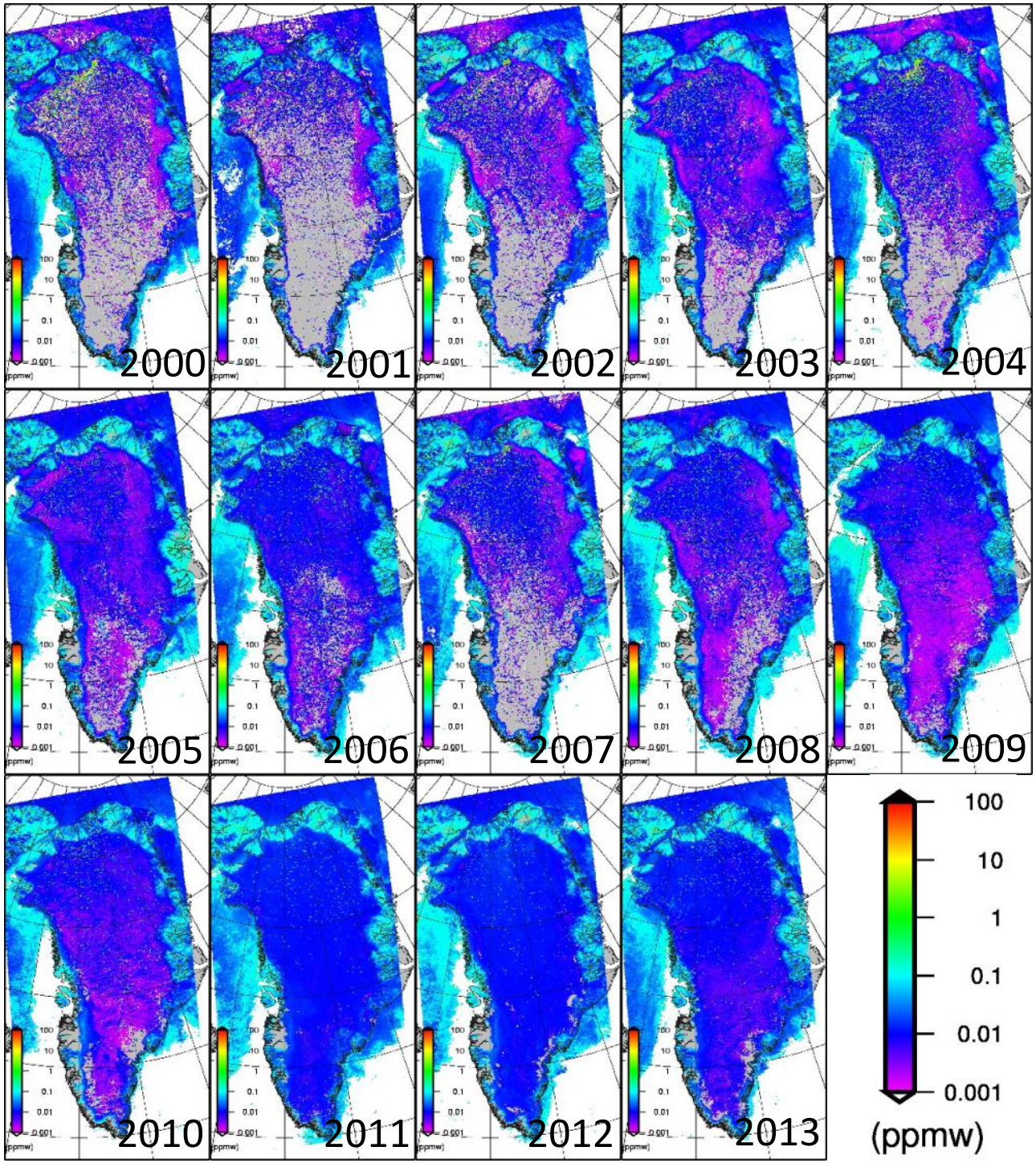
Snow grain size (Rs1) - monthly average in July



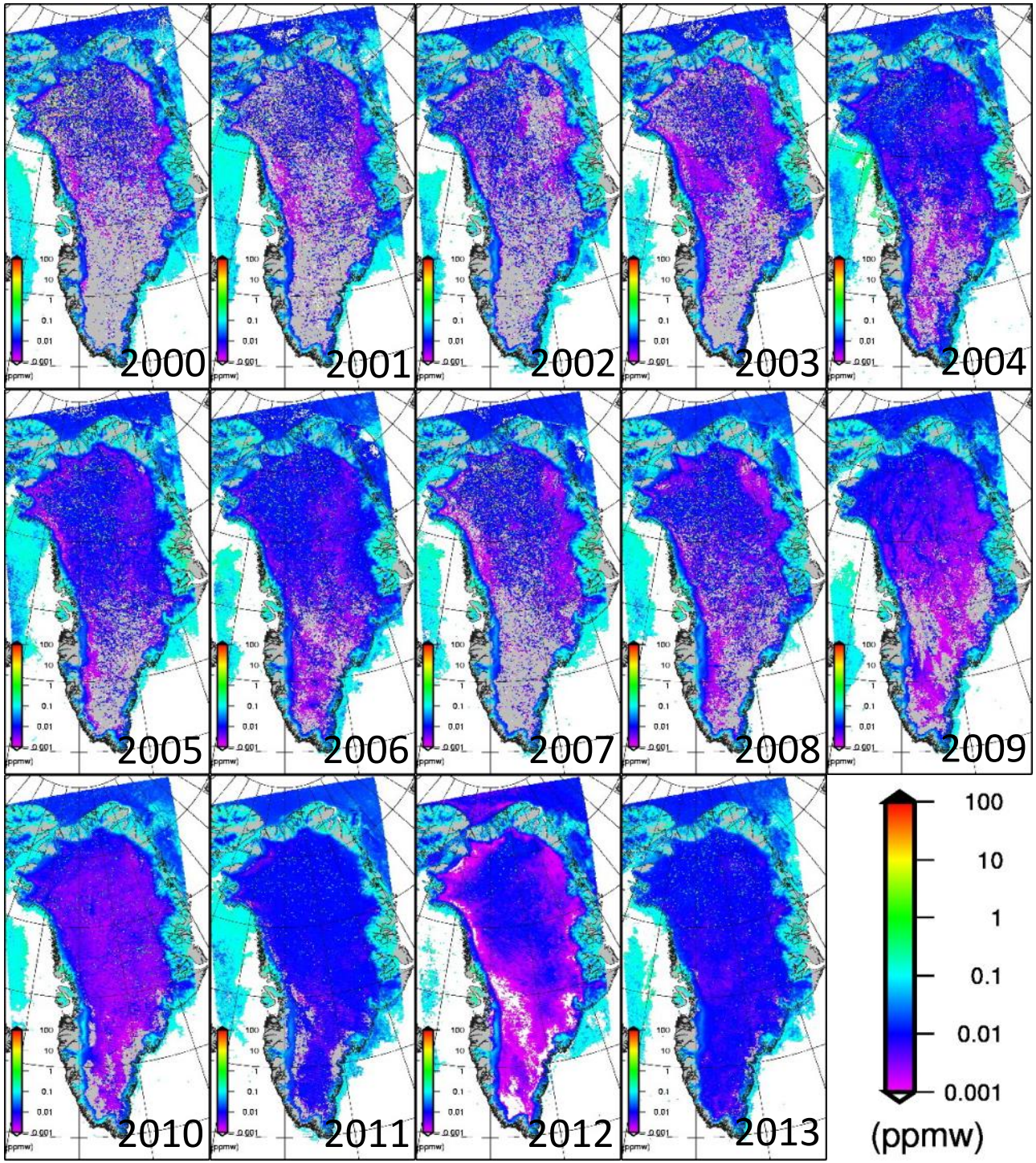
Snow grain size (Rs2) - monthly average in July



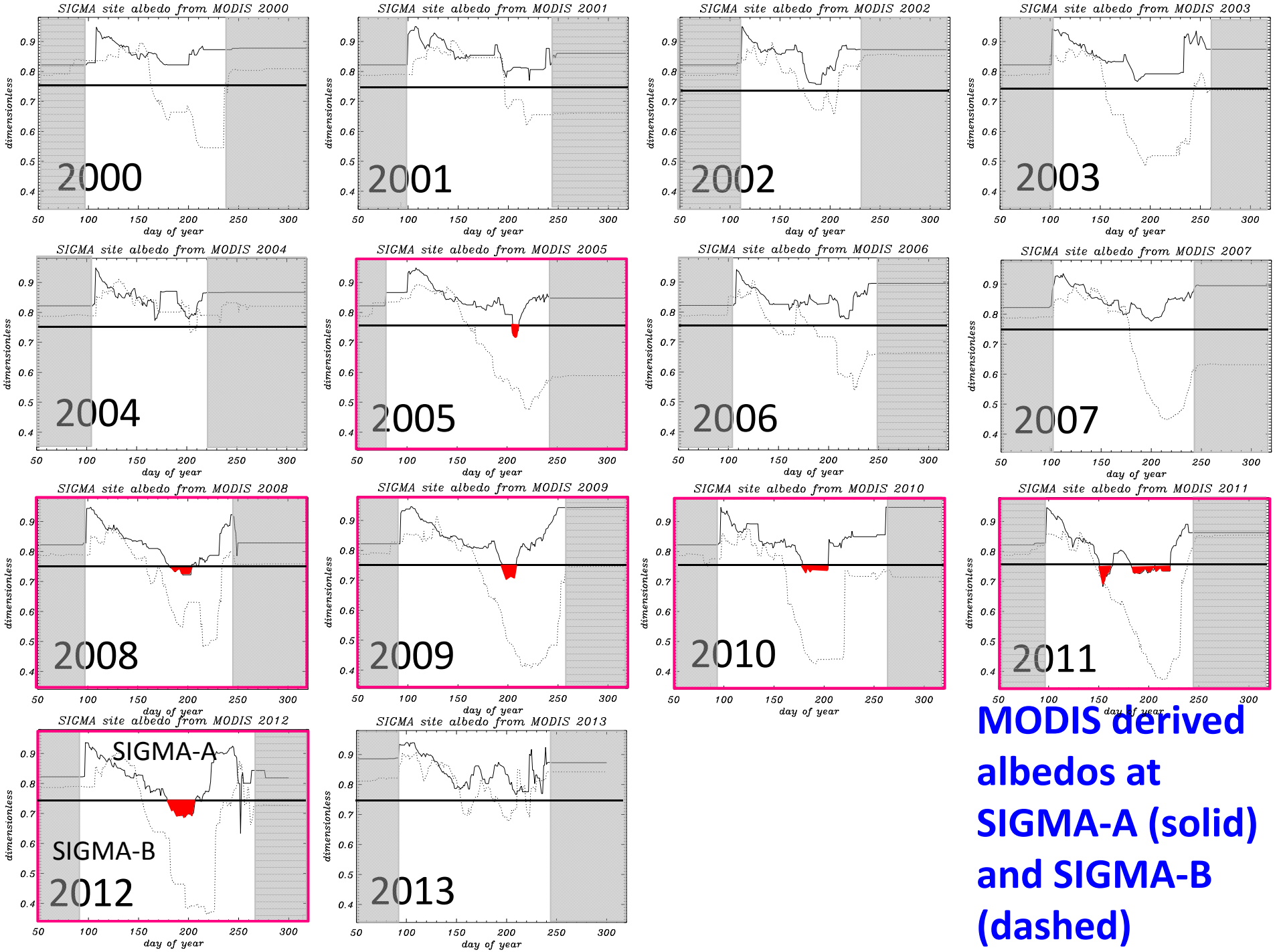
Snow grain size (Rs2) - monthly average in July



Snow impurity conc. (Cs) - monthly average in June

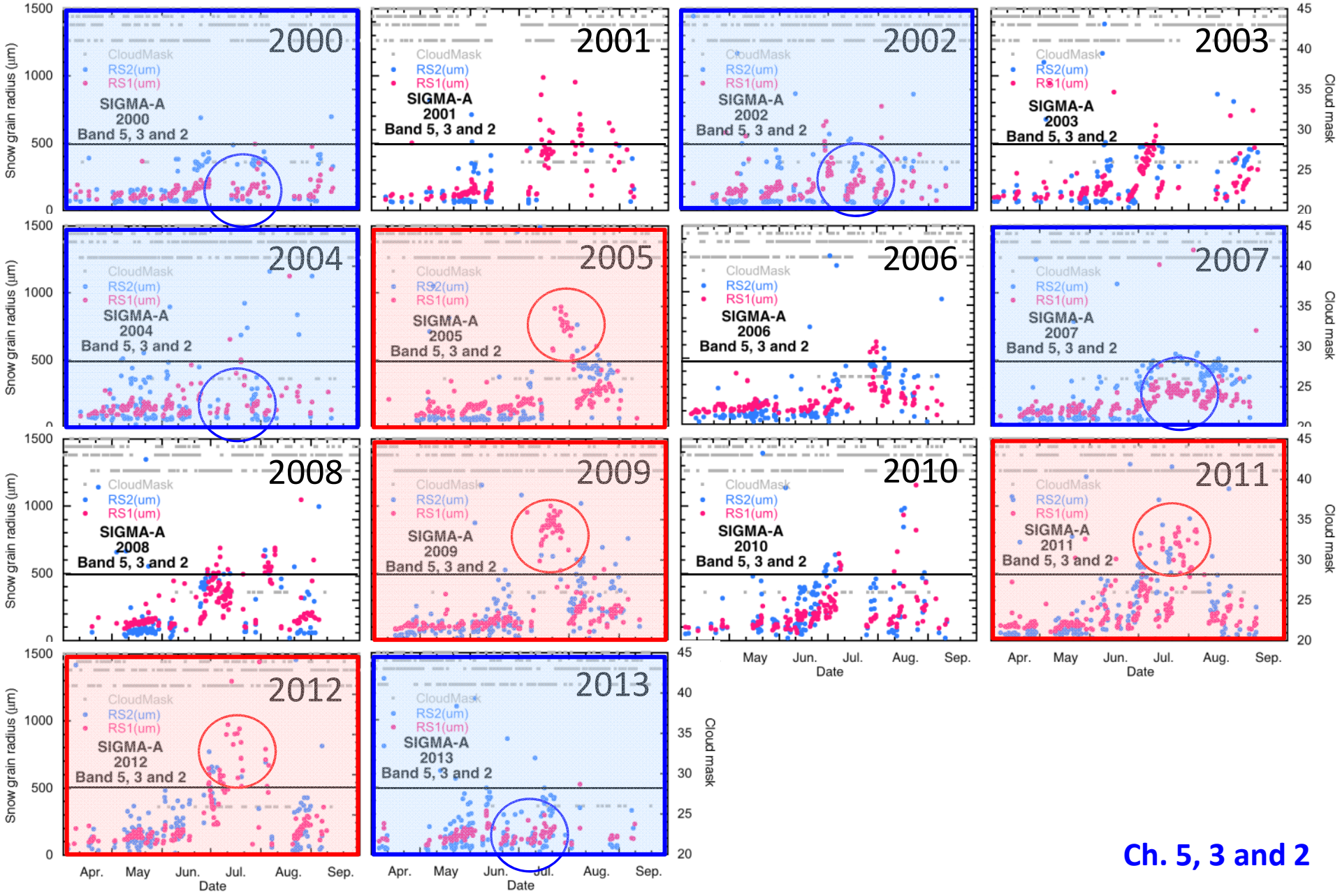


Snow impurity conc. (Cs) - monthly average in July



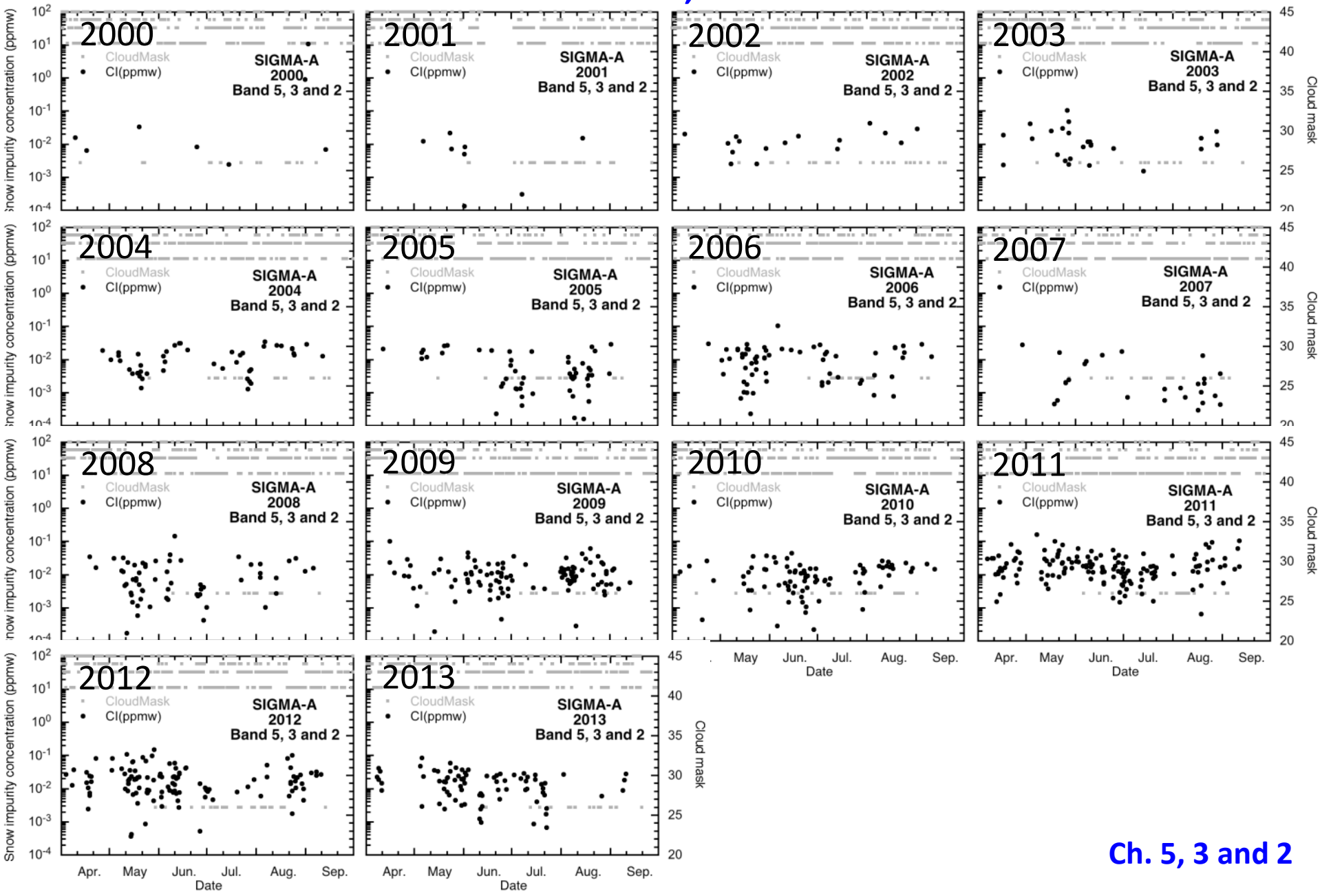
MODIS derived albedos at SIGMA-A (solid) and SIGMA-B (dashed)

Seasonal variations of MODIS-derived snow grain size for surface and subsurface layer at SIGMA-A, Greenland



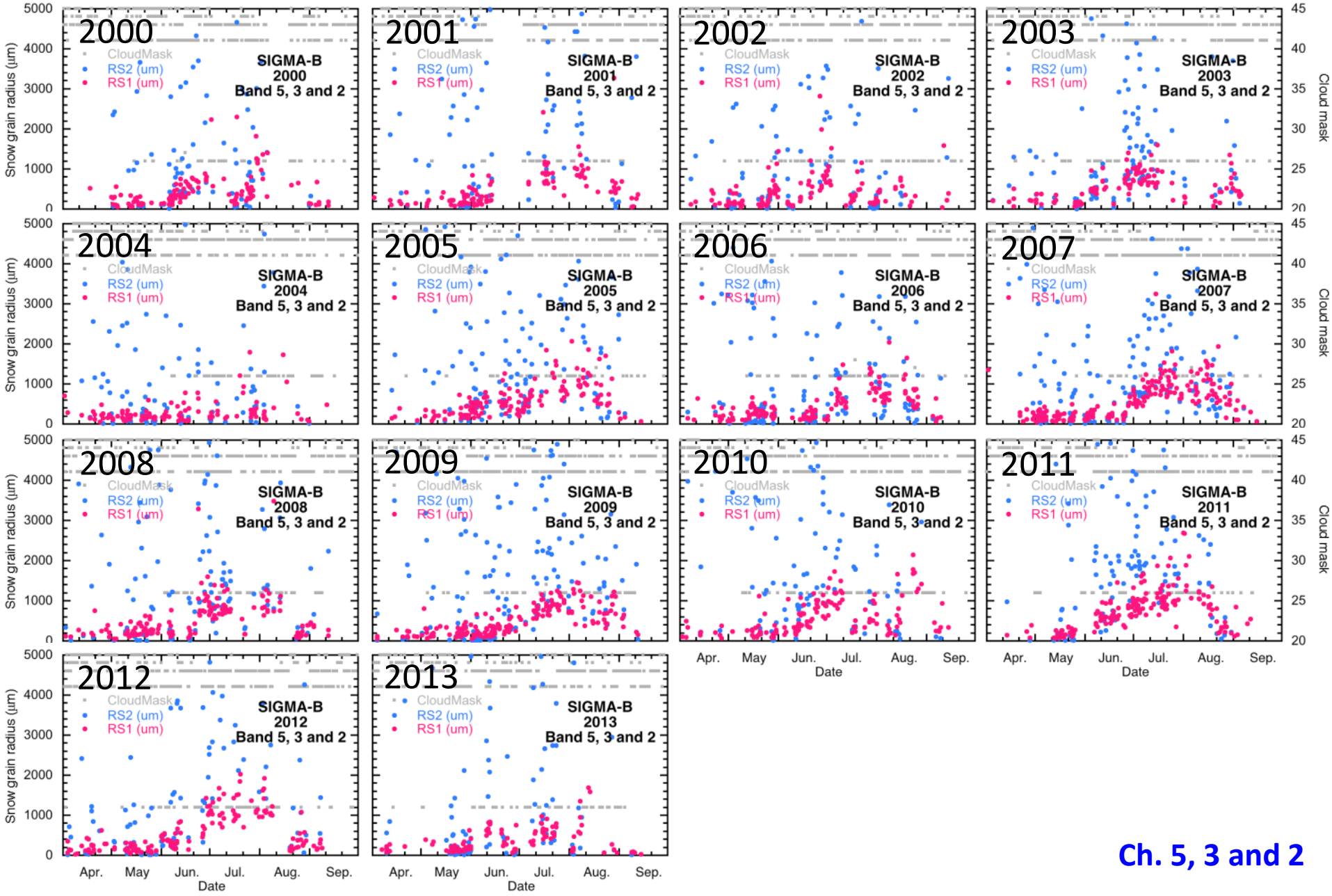
Ch. 5, 3 and 2

Seasonal variation of MODIS-derived soot concentration at SIGMA-A, Greenland



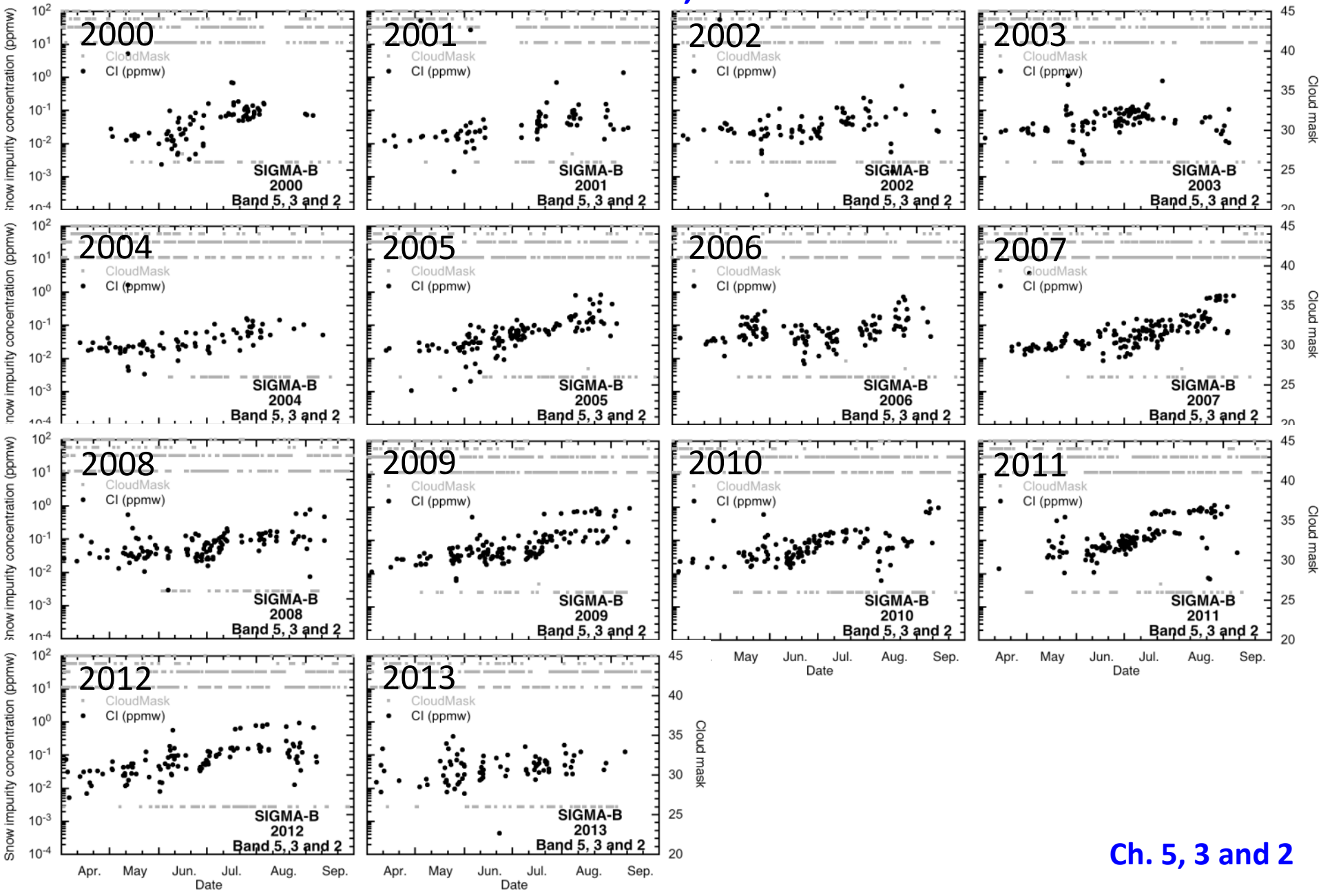
Ch. 5, 3 and 2

Seasonal variations of MODIS-derived snow grain size for surface and subsurface layer at SIGMA-B, Greenland



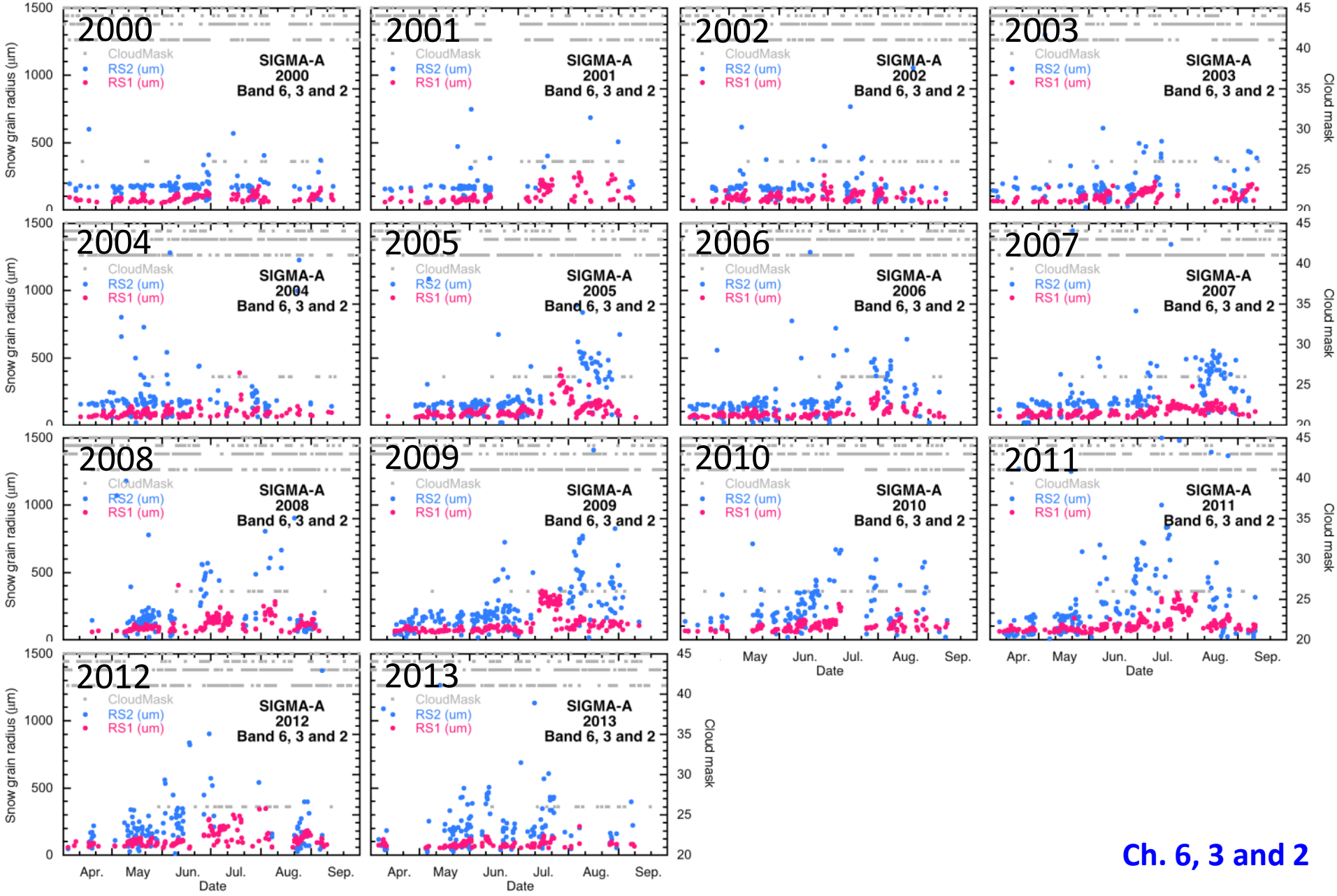
Ch. 5, 3 and 2

Seasonal variation of MODIS-derived soot concentration at SIGMA-B, Greenland



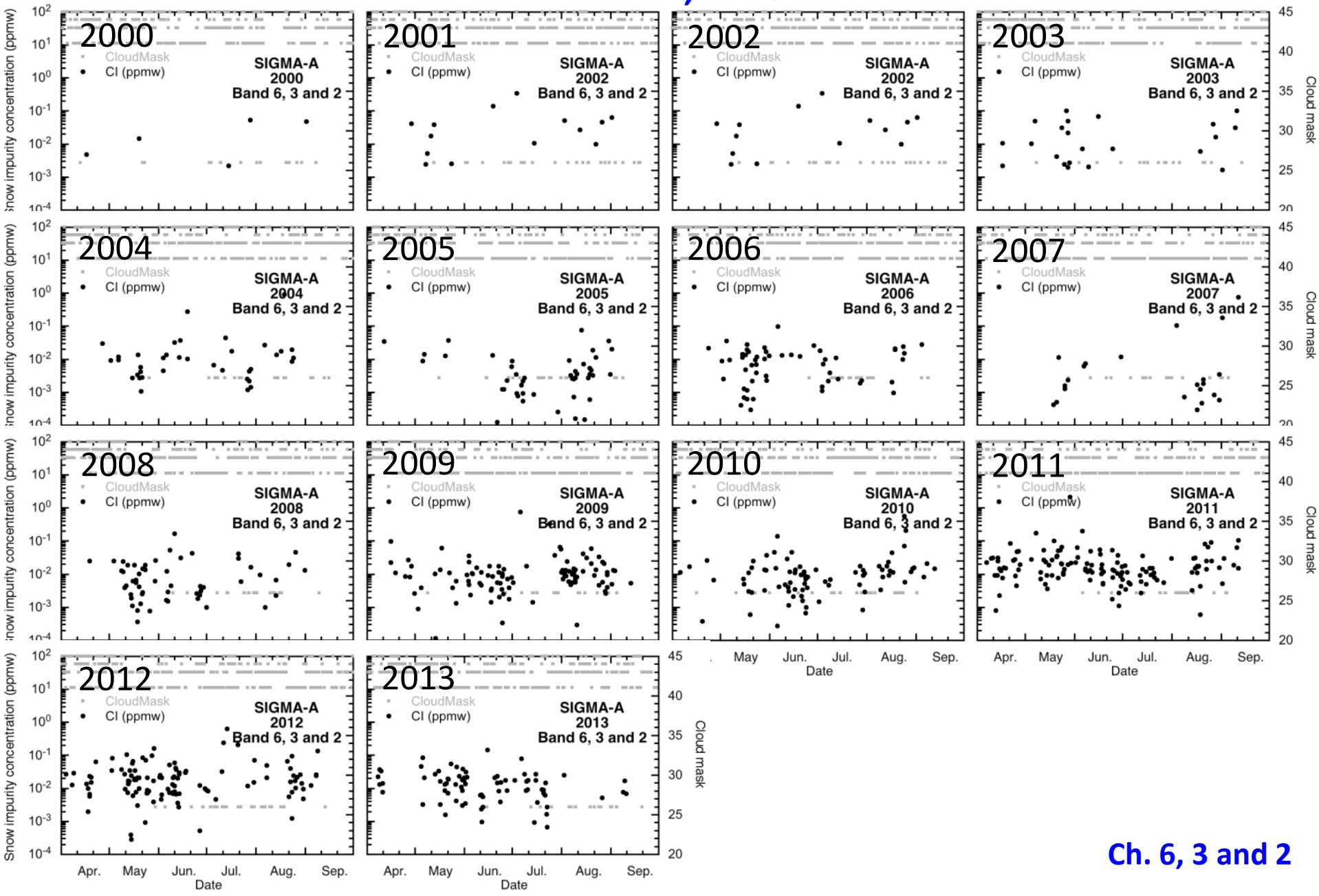
Ch. 5, 3 and 2

Seasonal variations of MODIS-derived snow grain size for surface and subsurface layer at SIGMA-A, Greenland



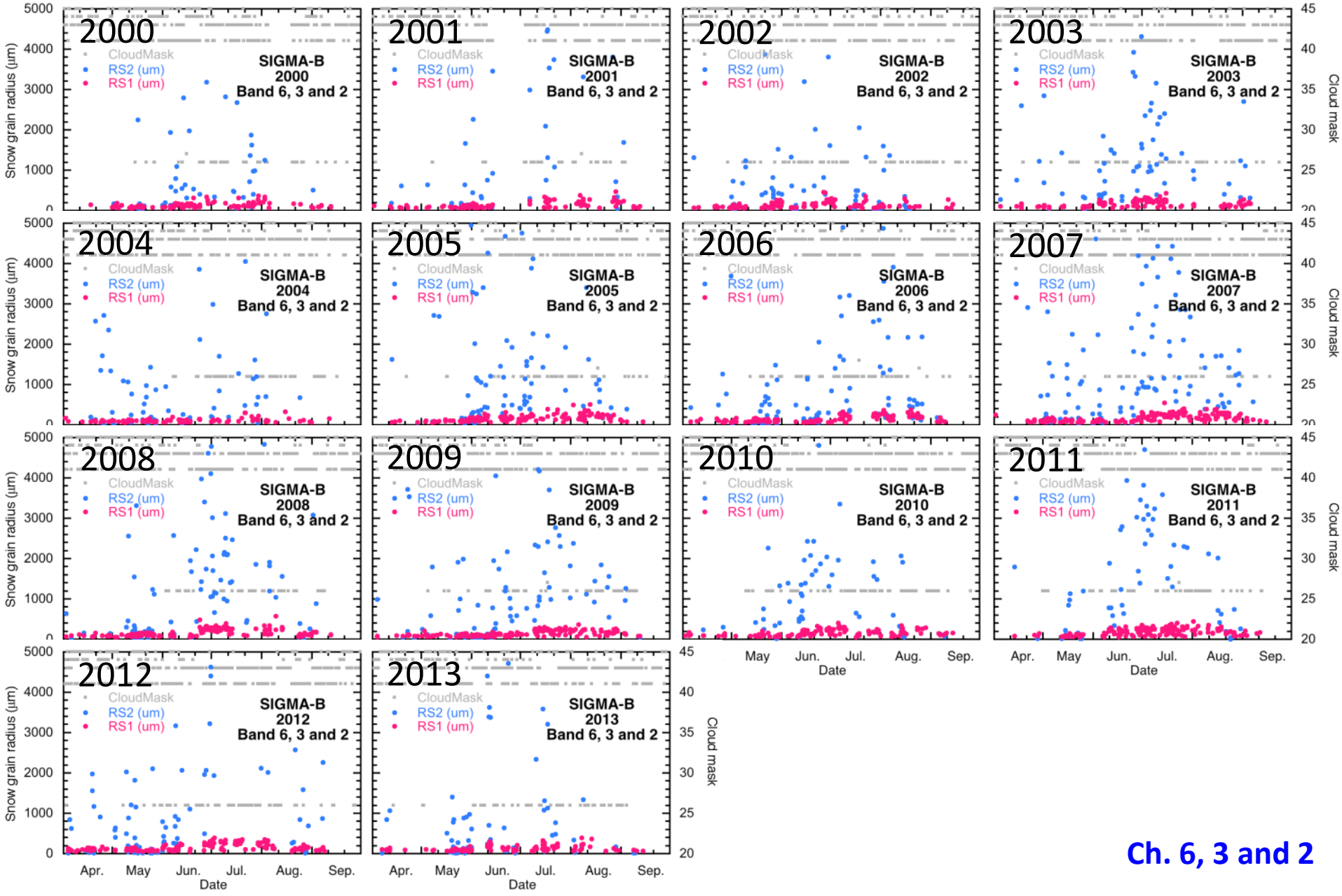
Ch. 6, 3 and 2

Seasonal variation of MODIS-derived soot concentration at SIGMA-A, Greenland



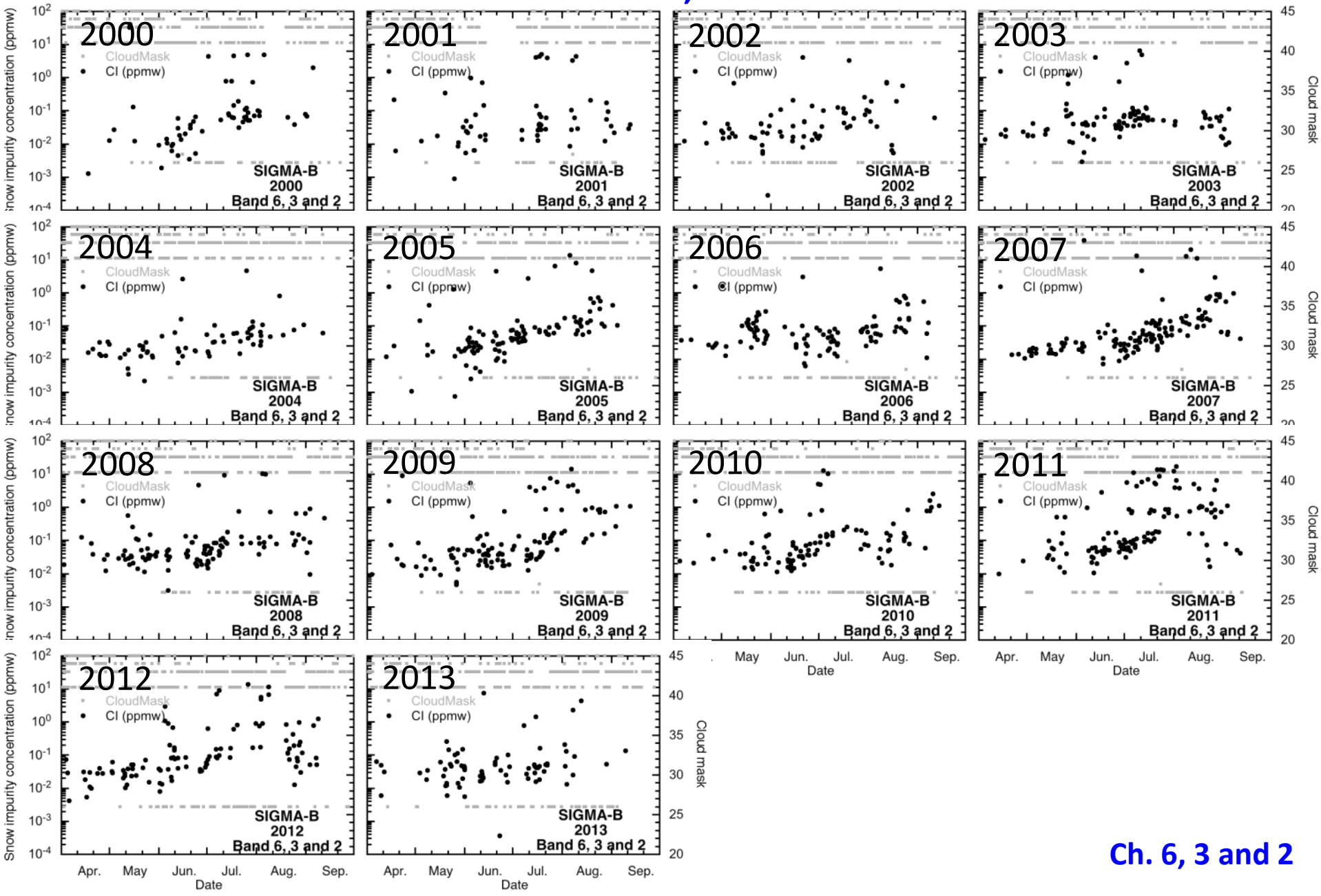
Ch. 6, 3 and 2

Seasonal variations of MODIS-derived snow grain size for surface and subsurface layer at SIGMA-B, Greenland



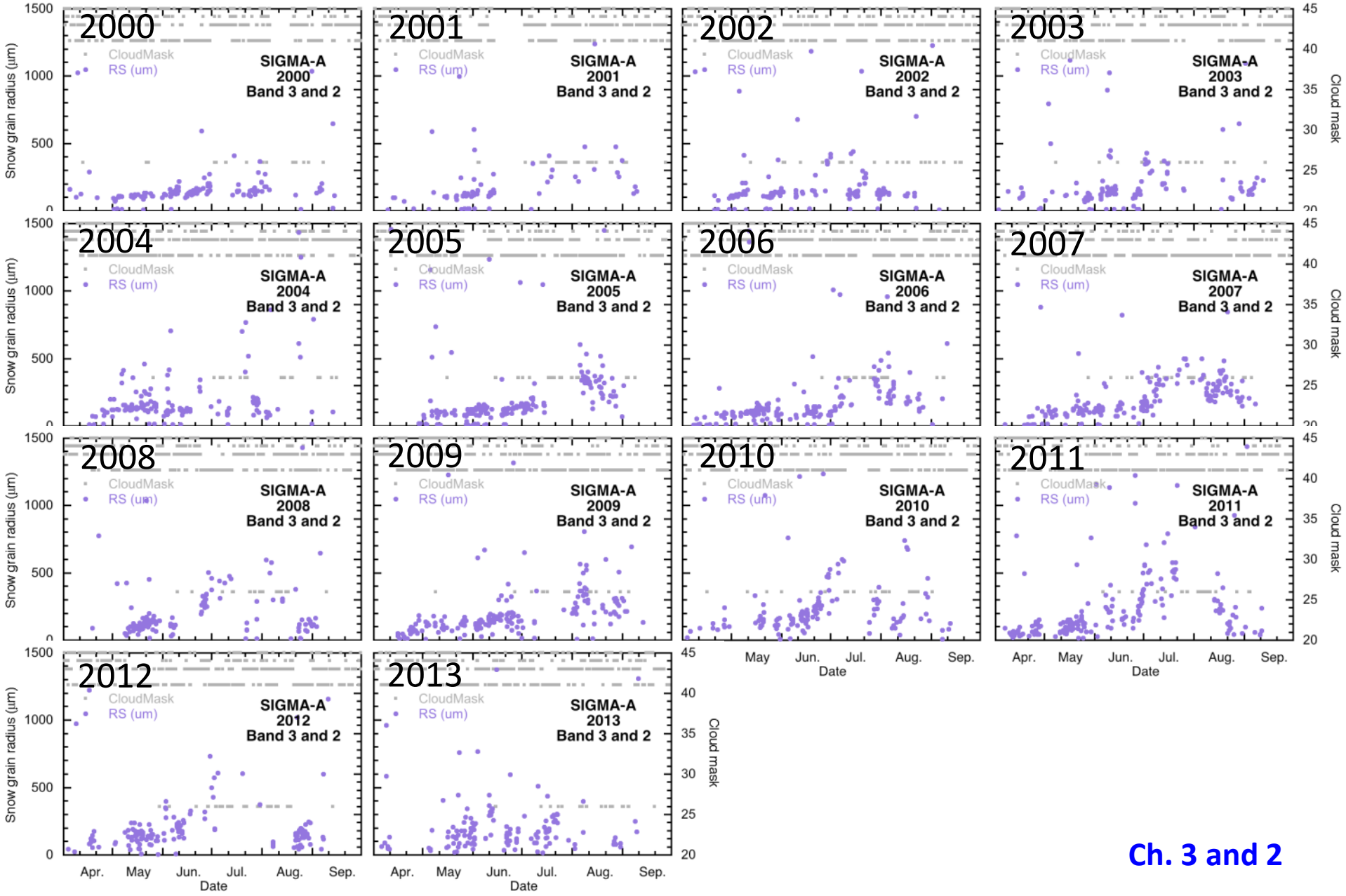
Ch. 6, 3 and 2

Seasonal variation of MODIS-derived soot concentration at SIGMA-B, Greenland



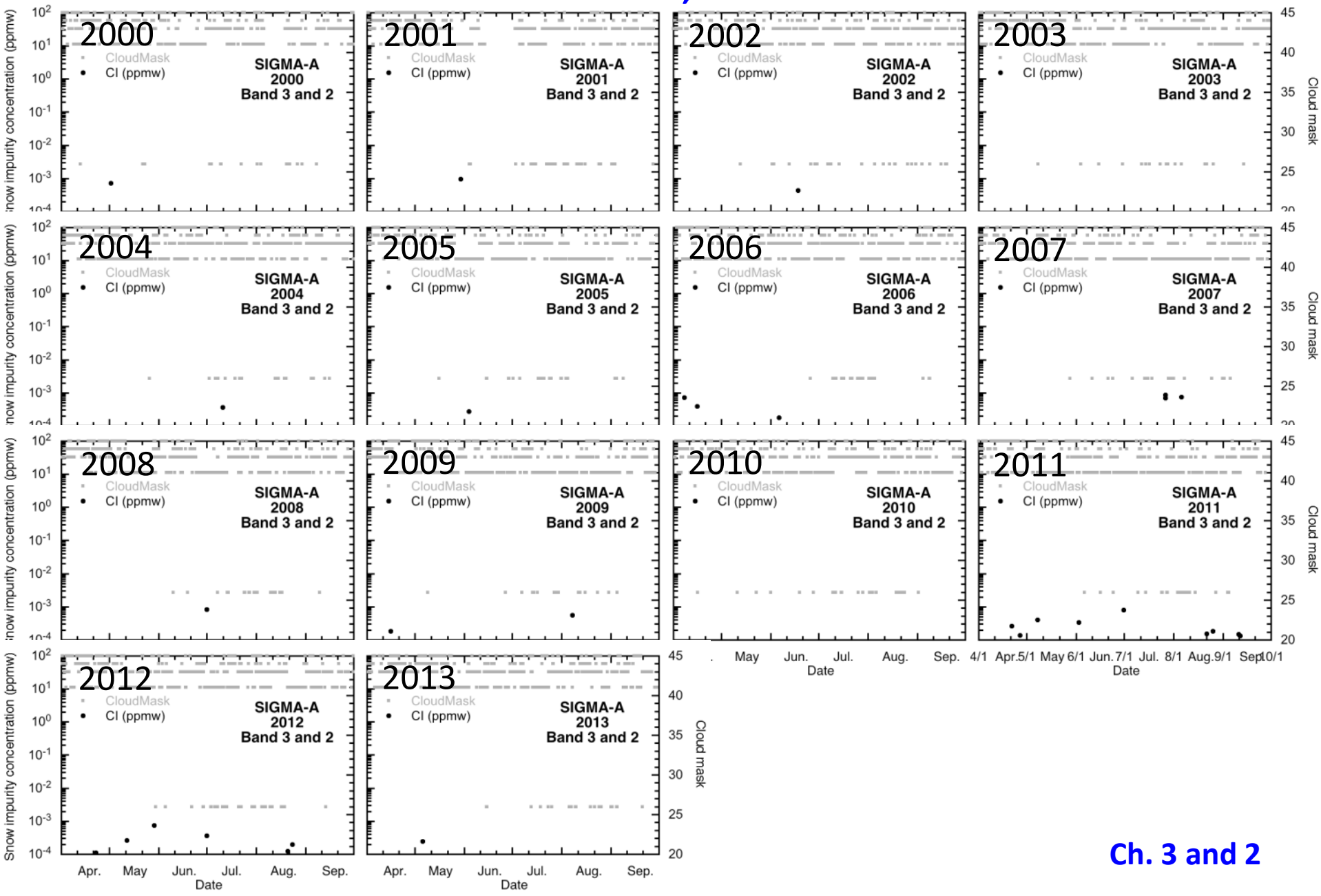
Ch. 6, 3 and 2

Seasonal variations of MODIS-derived snow grain size at SIGMA-A, Greenland



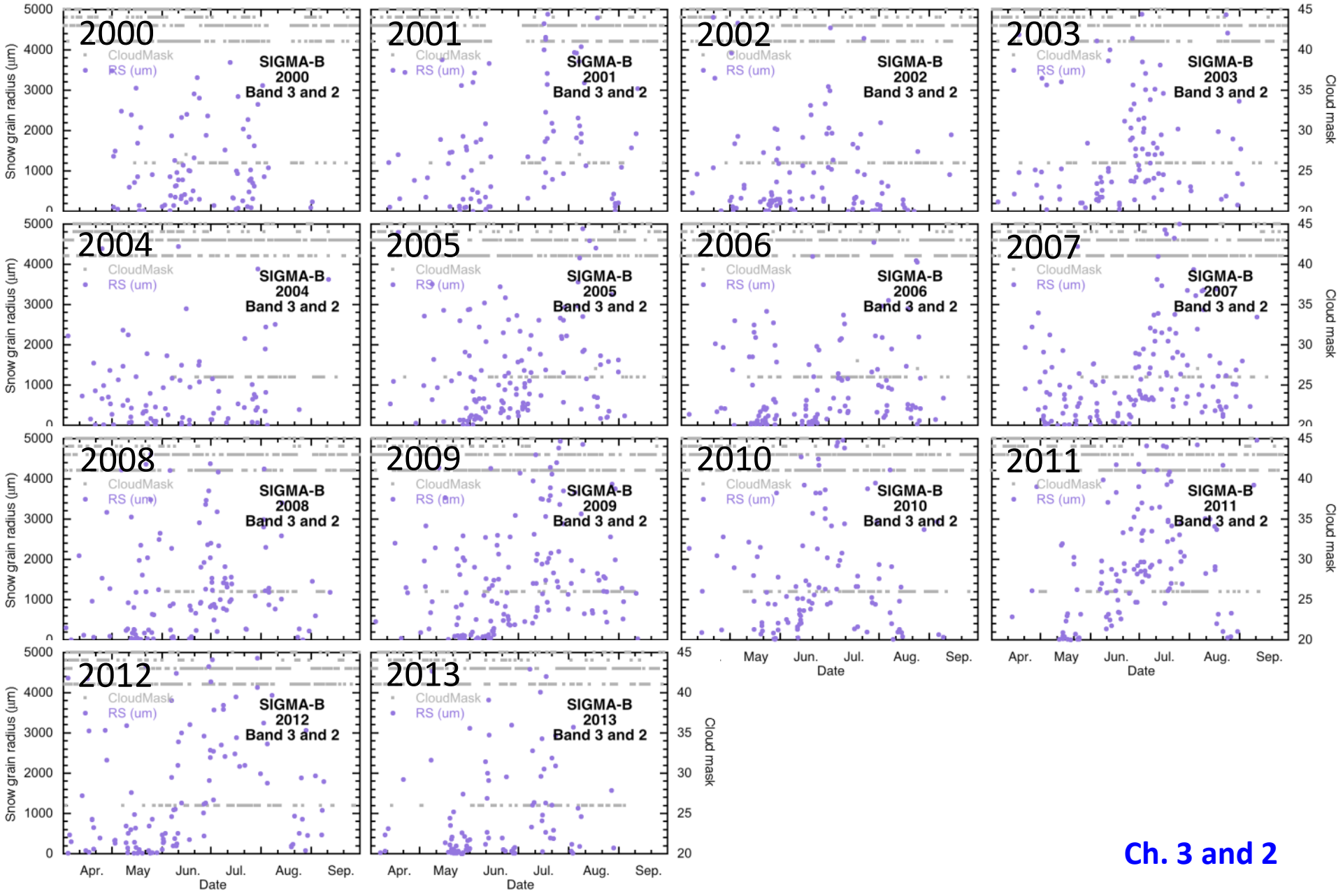
Ch. 3 and 2

Seasonal variations of MODIS-derived soot concentration at SIGMA-A, Greenland



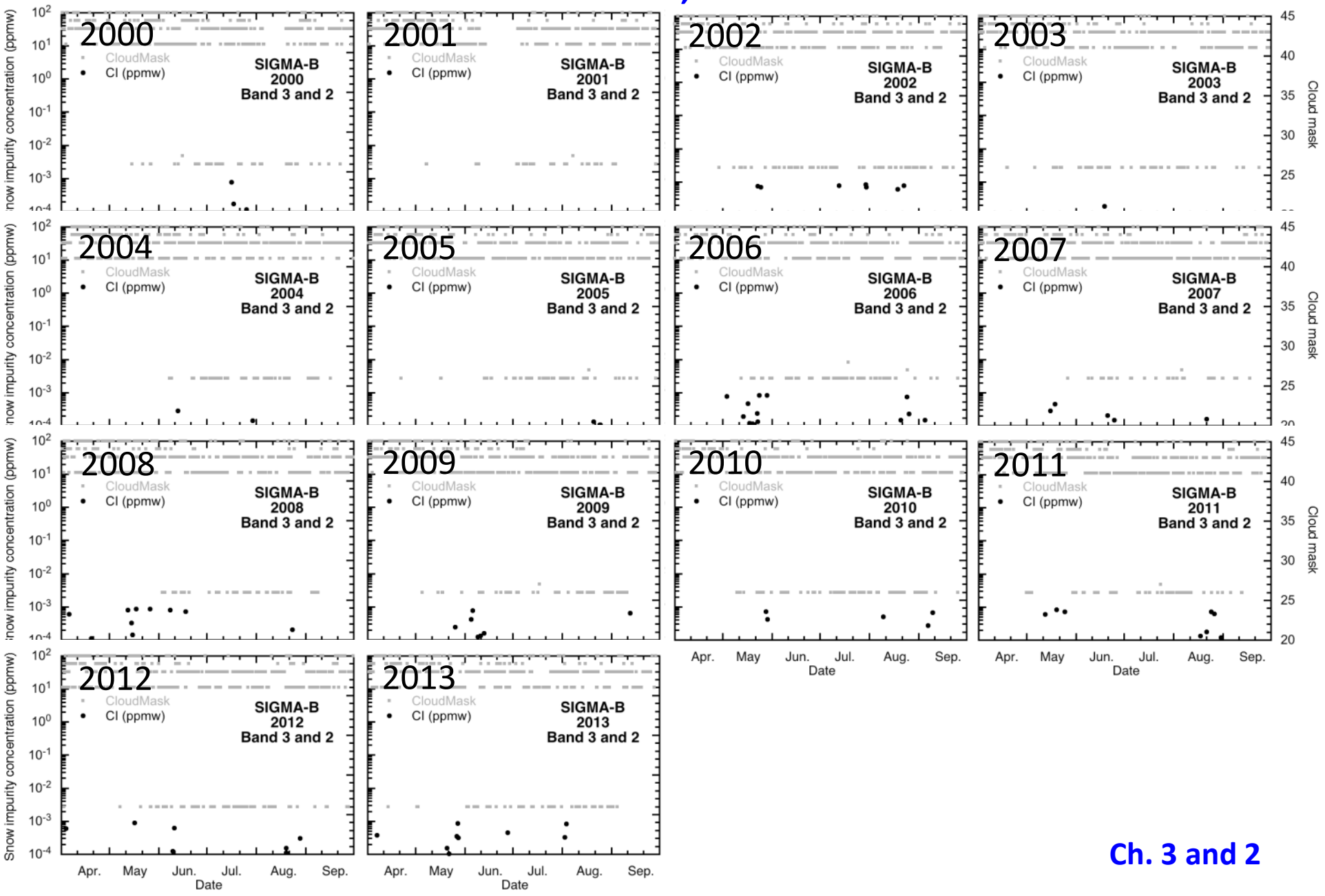
Ch. 3 and 2

Seasonal variations of MODIS-derived snow grain size at SIGMA-B, Greenland



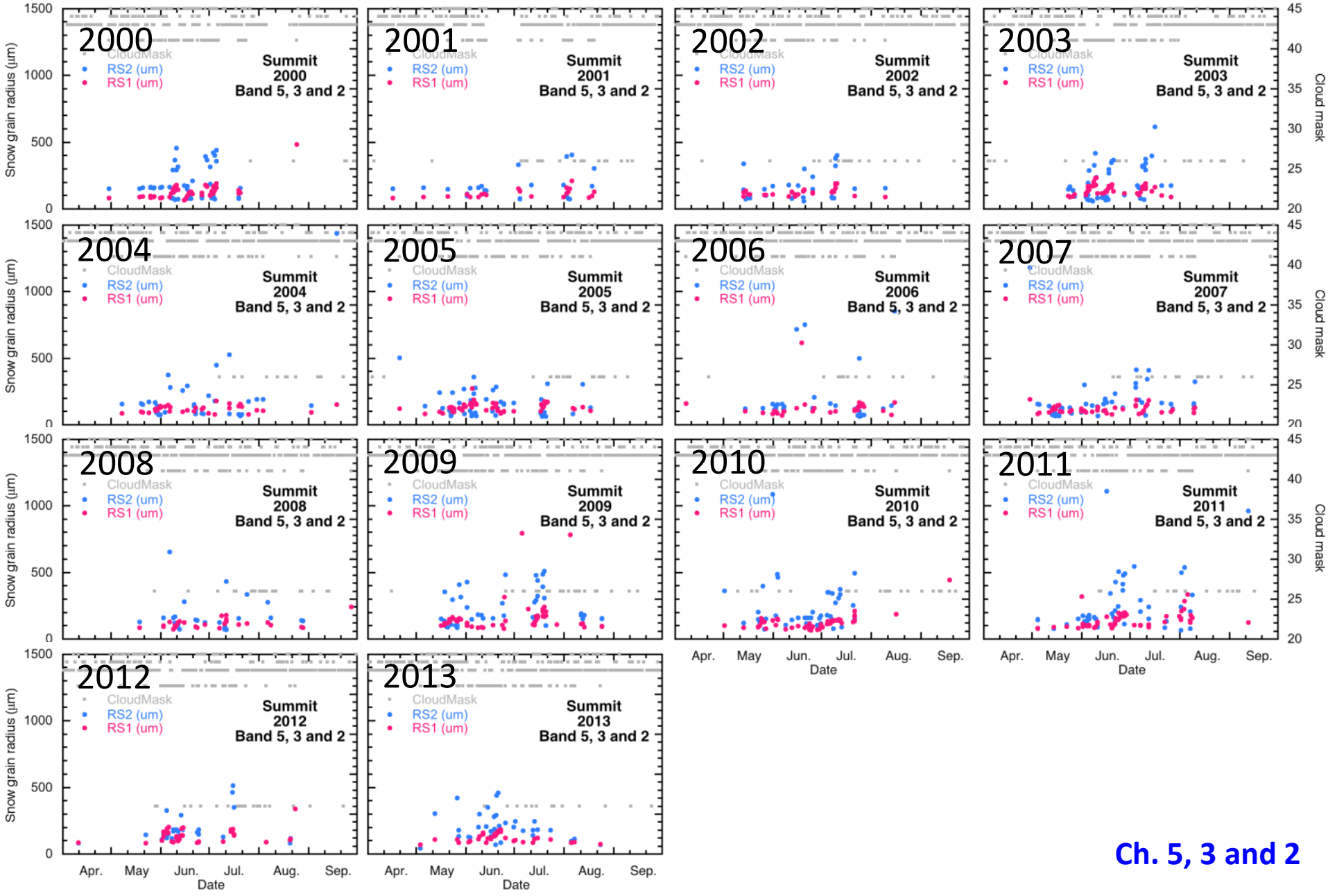
Ch. 3 and 2

Seasonal variations of MODIS-derived soot concentration at SIGMA-B, Greenland



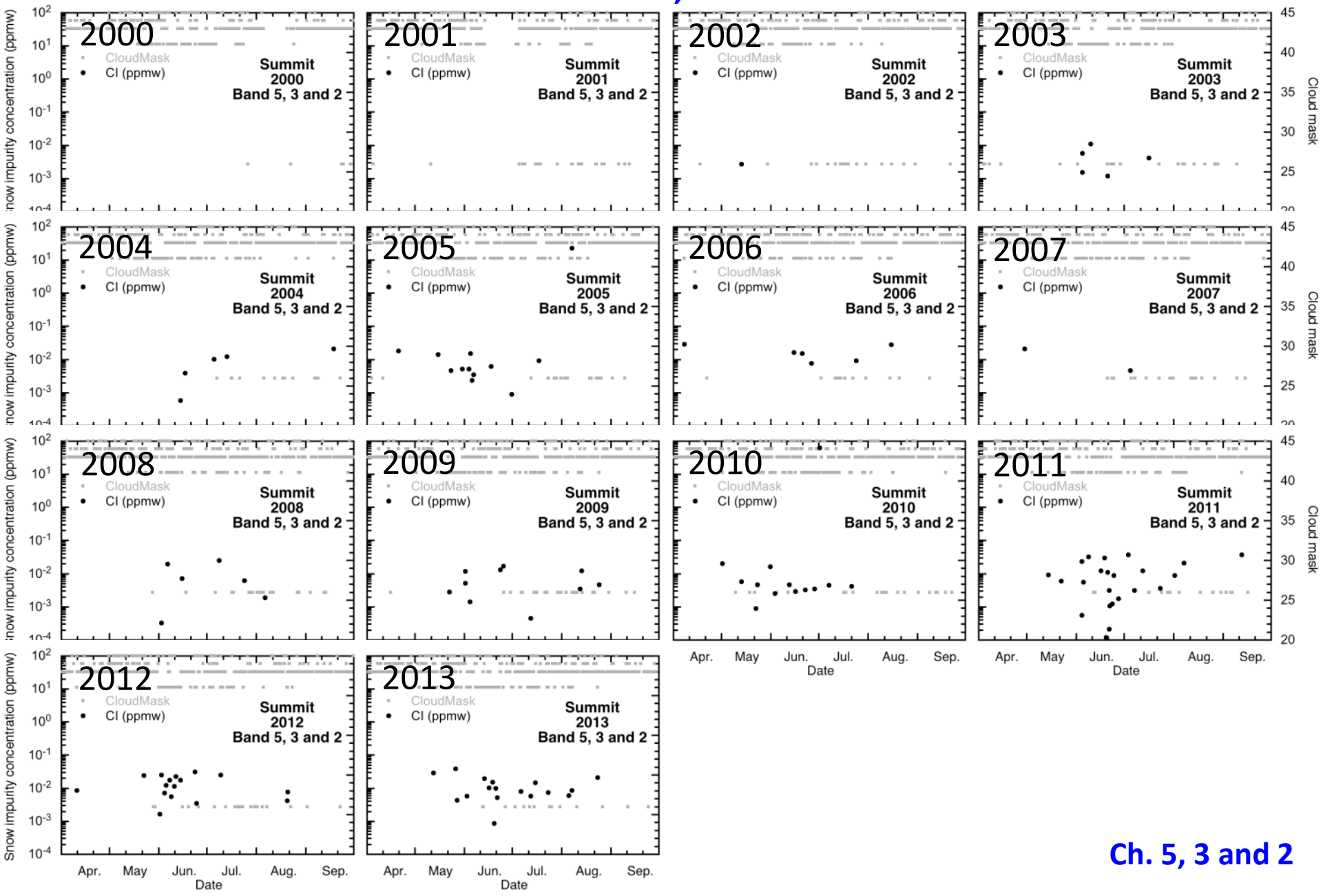
Ch. 3 and 2

Seasonal variation of MODIS-derived snow grain size at Summit, Greenland



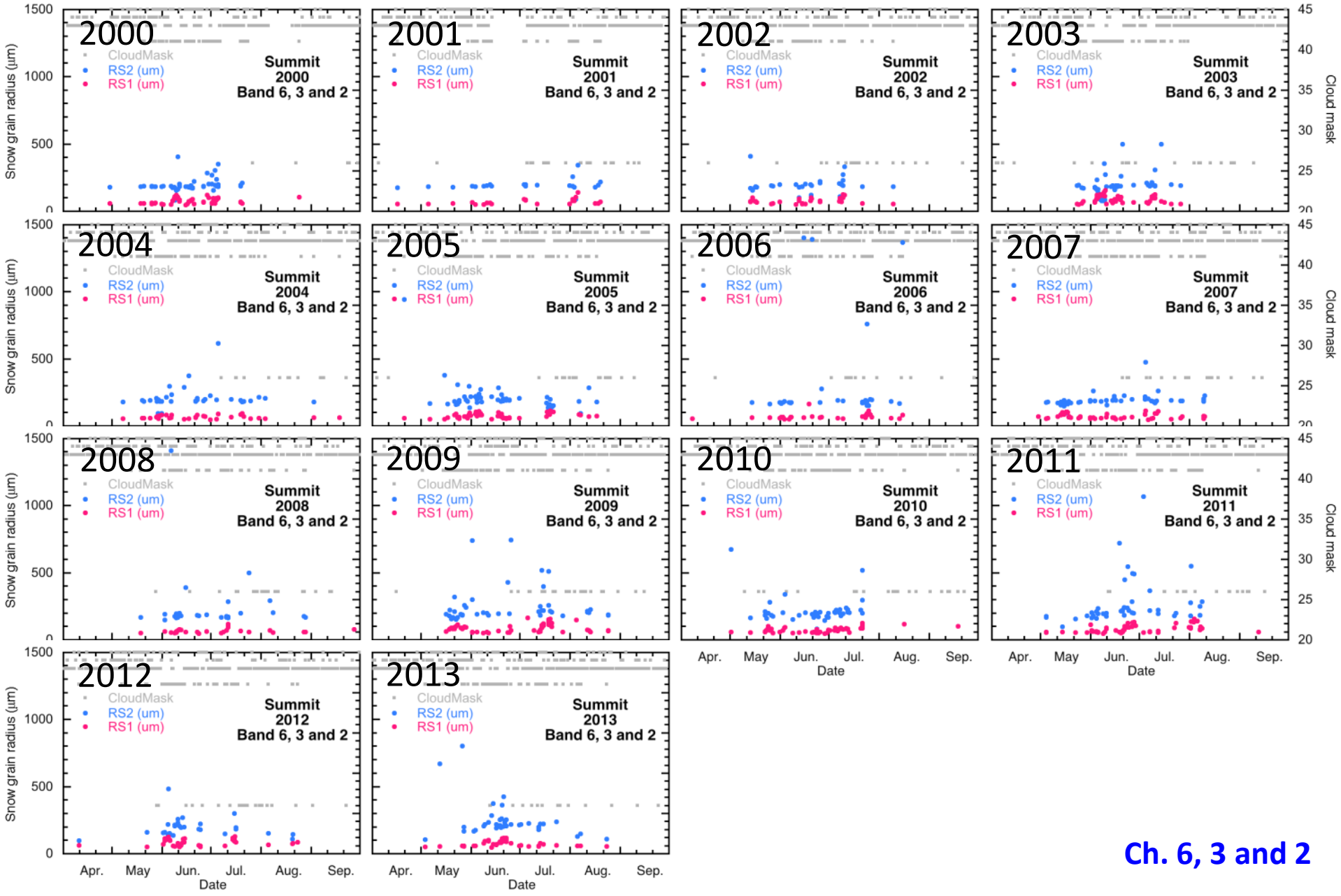
Ch. 5, 3 and 2

Seasonal variation of MODIS-derived soot concentration at Summit, Greenland



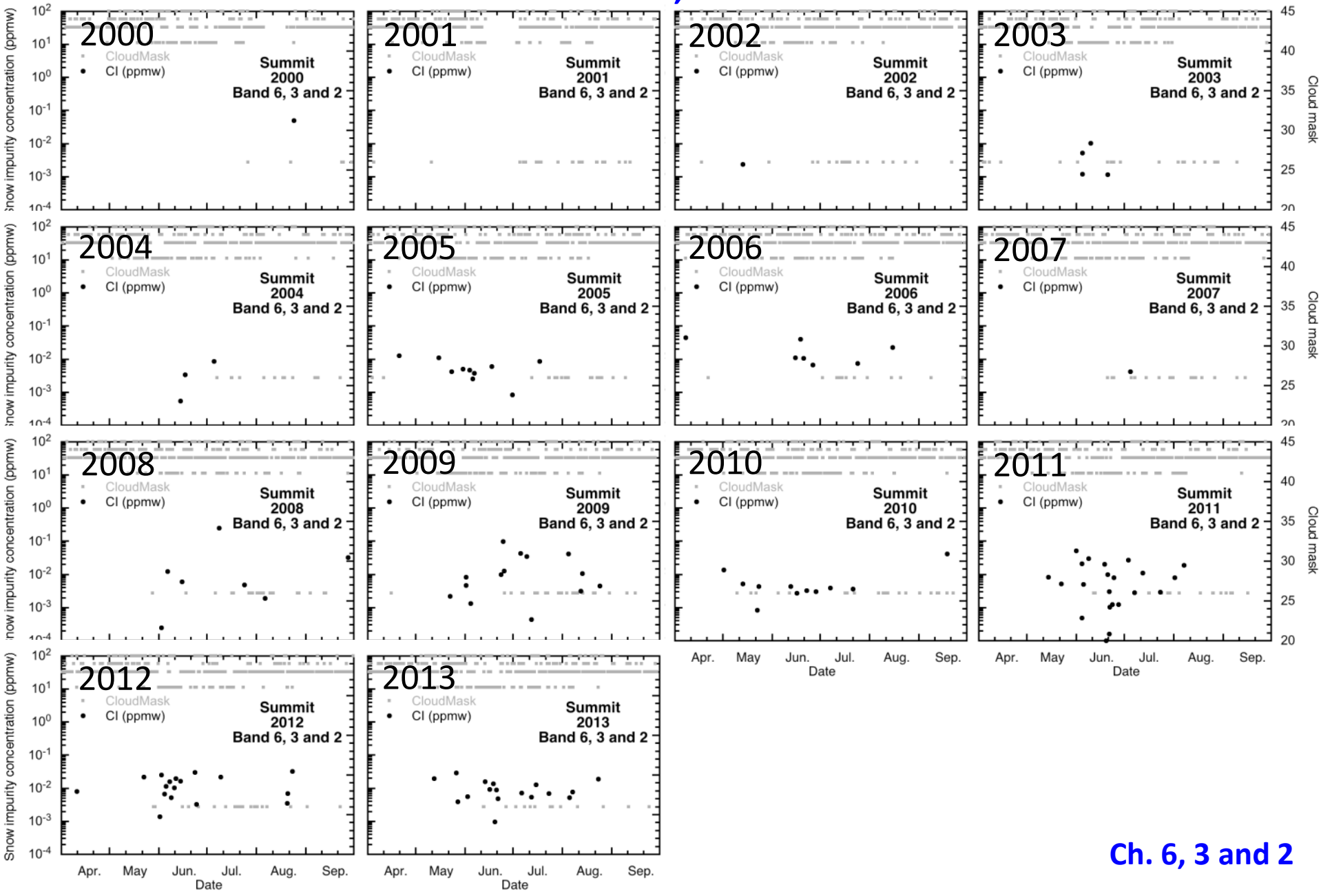
Ch. 5, 3 and 2

Seasonal variation of MODIS-derived snow grain size at Summit, Greenland



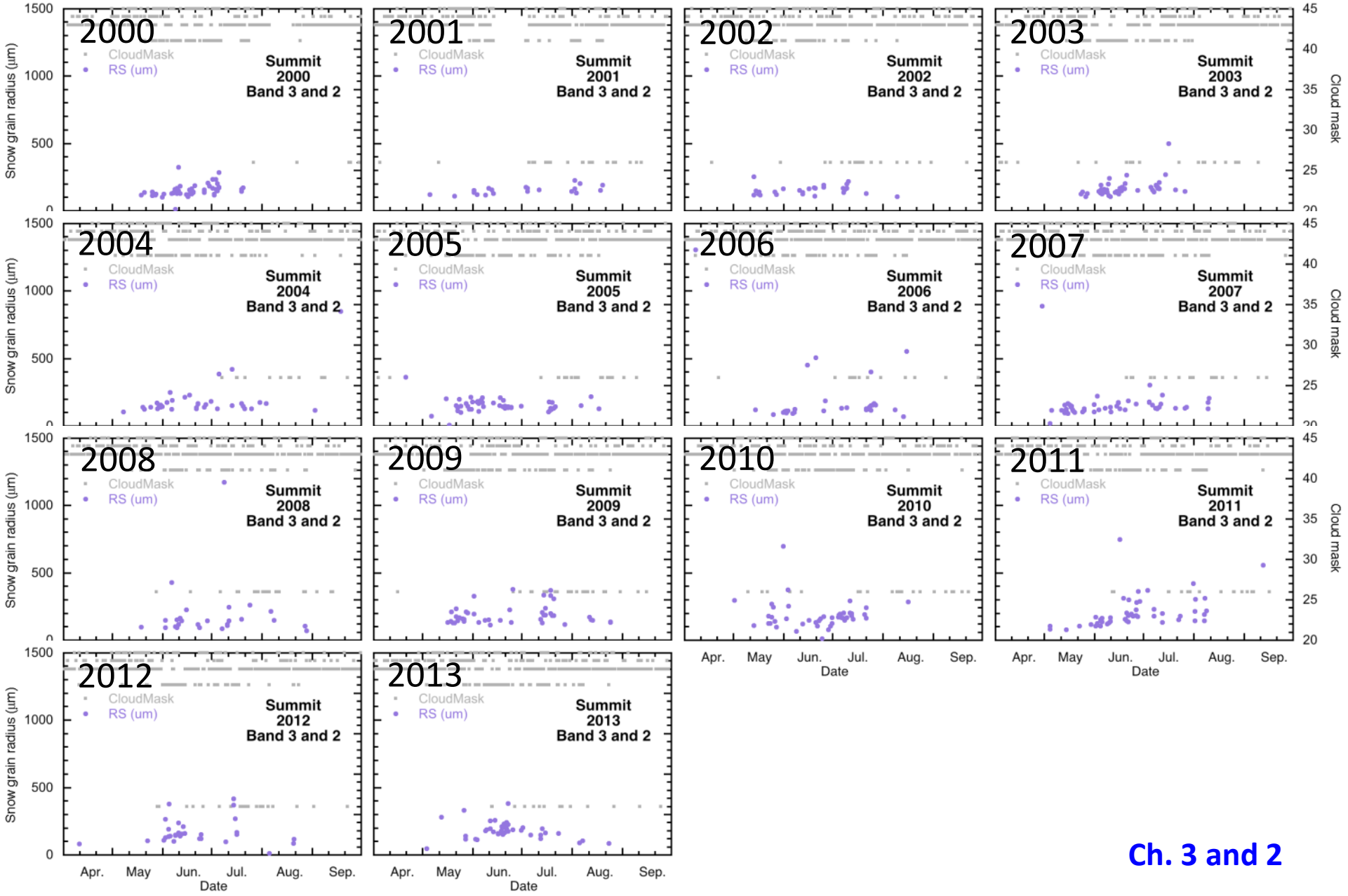
Ch. 6, 3 and 2

Seasonal variation of MODIS-derived soot concentration at Summit, Greenland



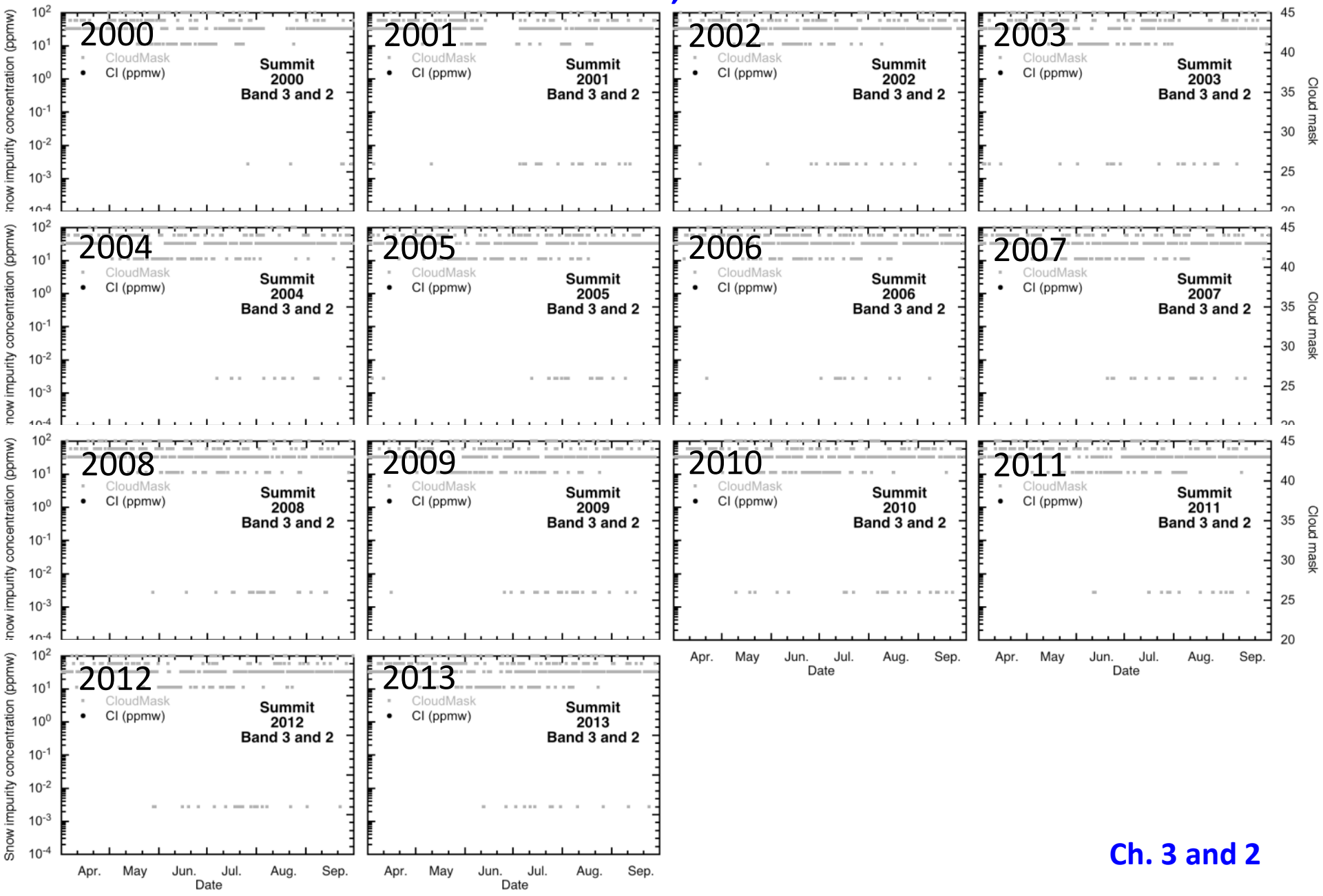
Ch. 6, 3 and 2

Seasonal variations of MODIS-derived snow grain size at Summit, Greenland



Ch. 3 and 2

Seasonal variations of MODIS-derived soot concentration at Summit, Greenland



Ch. 3 and 2